WEST INDIAN BULLETIN

THE JOURNAL OF THE IMPERIAL AGRICULTURAL DEPARTMENT FOR THE WEST INDIES.

VOL. XIX. No. 2.

(*Issued March 31, 1922.*)

CONTENTS.

Soil Studies in Shrinkage—Humidity—Liming—Soils of Montserrat—Syrup Technology—Physiology of Cotton—Prevalence of Pests and Diseases.

IMPERIAL MYCOLOGICAL INSTITUTE
25 JULY 1935

Price Sixpence.

Local Agents: The ADVOCATE Co., Ltd., Bridgetown, Barbados.
London Agents: Messrs. DULAU & Co., 34-36, Margaret Street, Cavendish Square, W. 1.
WEST INDIA COMMITTEE, 15, Seething Lane, E.C.

ISSUED BY THE COMMISSIONER. BARBADOS.

Imperial Department of Agriculture

FOR THE WEST INDIES.

HEAD OFFICE—BARBADOS.

Imperial Commissioner of Agriculture for the West Indies	SIR FRANCIS WATTS, K.C.M.G., D.Sc., F.I.C., F.C.S.

Scientific Staff.

Scientific Assistant and Assistant Editor of Publications	W. R. DUNLOP.
Entomologist	H. A. BALLOU, M.Sc.
Mycologist	S. F. ASHBY, B.Sc.
Botanist	T. G. MASON, M.A., Sc.B., Agr. B. (Trin. Col., Dub.)
Chemist...	F. HARDY, M.A., Dip. Ag. (Cantab.).
Geologist for Special Investigations ...	K. W. EARLE, M.Sc., F.G.S.*
Assistant for Cotton Research	———†

Clerical Staff.

Chief Clerk	A. G. HOWELL.
Clerical Assistants .	L. A. CORBIN. K. R. C. FOSTER.
Typist	MISS B. ROBINSON.
Assistant Typist	MISS L. BRANCH.
Assistant for Publications	A. B. PRICE, Fell. Journ. Inst.
Messenger	E. E. LEACOCK.

**Provided by the Colonial Research Committee.*
†Provided by the Empire Cotton Growing Committee of the Board of Trade.

BARBADOS.

Department of Agriculture.

Director of Agriculture	J. R. BOVELL, I.S.O., F.C.S.,
Assistant Director ...	B. A. BOURNE, B.Sc.
First Field Assistant ...	H. O. PROVERBS.
Second Field Assistant ...	C. O. HAYNES.
Assistant in charge of the Nurseries	C. L. DAVIS, (Acting).
Chief Clerk	C. B. FOSTER, (Acting).
Second Clerk	D. G. RAMSEY.
Third Clerk	MISS V. BIRKETT.
Inspector Mosaic Diseases (Eradication) Act.	H. O. RAMSEY, (Acting).

BRITISH GUIANA.

BOARD OF AGRICULTURE.

President	H.E. THE GOVERNOR.
Chairman	THE DIRECTOR OF SCIENCE AND AGRICULTURE.
Deputy Chairman	THE ASSISTANT DIRECTOR.
Secretary	E. M. PETERKIN.
Editor, *Journal of the Board of Agriculture*	

Honorary Members: SIR DANIEL MORRIS, K.C.M.G., etc.; SIR FREDERICK M. HODGSON, K.C.M.G.; SIR FRANCIS WATTS, K.C.M.G., etc; SIR WALTER EGERTON, K.C.M.G.; J. J. QUELCH, B.Sc.

And twenty-two members appointed by the Governor.

DEPARTMENT OF SCIENCE AND AGRICULTURE.

Director and Government Analyst and Geologist	THE HON. SIR J. B. HARRISON, C.M.G., M.A., F.I.C., F.G.S., etc.
Assistant Director	

DEPUTY DIRECTORS OF AGRICULTURE.

North West District	E. H. KING, Commissioner.
N. & S. Essequibo Coast and River	S. H. BAYLEY, Superintendent Onderneeming Farm.
Rupununi District	Dr. W. E. ROTH, Commissioner.

Head Office.

Secretary	E. M. PETERKIN.
Assist. Clerk and Librarian	MISS M. VAN NOOTEN.
Scientific Assist. to Director	C. L. C. BOURNE.

And two Clerical Assistants.

Chemical Division.

Deputy Government Analyst	W. FRANCIS.

And three Assistant Analysts.

Botanical and Agricultural Divisions.

Superintendent of Botanic Gardens and Agricultural Stations	R. WARD.
Assistant Botanist and Mycologist	
Horticultural Superintendent	A. A. ABRAHAM.

Three Agricultural Instructors,
Four Agricultural Assistants,
Nine District Agricultural Instructors,
And two Clerical Assistants.

Veterinary Division.

Veterinary Surgeon	A. SETON MILNE, M.R.C.V.S., F.V.M.S.

Biological Division.

Economic Biologist	
Assistant Entomologist	L. D. CLEARE, Jr., F.E.S.

Geological Division.

Geological Surveyor	E. E. WINTER, B.Sc.

BRITISH GUIANA SUGAR PLANTERS' EXPERIMENT STATIONS' COMMITTEE.

THE DIRECTOR OF SCIENCE AND AGRICULTURE, Chairman (ex officio); THE HON. R. E. BRASSINGTON (Chairman, B. G. Sugar Planters Association), R. STRANG, Esq., Pln. Uitvlugt, W. C., Demerara; W.M.B. SHIELDS, Esq., Messrs. Dawson & Co., Berbice; J. C. GIBSON, Esq., Pln. Port Mourant, Berbice; A. E. CRAIG, Esq., Pln. Ogle, E. C. Demerara; A. E. BRATT, Esq. Pln. Providce, E. B., Demerara; Secretary, C. L. C. BOURNE.

Superintendent of Stations—JAMES CRABTREE, M.Sc., F.I.C.

CONTENTS.

PAGE.

The Ecological Significance of Soil Shrinkage,

By T. G. Mason, M.A., Sc. B., Agr. B., Botanist on the Staff of the Imperial Department of Agriculture, for the West Indies 125

The Physiological Humidity of the Soil and its direct determination,

By T. G. Mason, M.A., Sc. B., Agr. B, Botanist on the Staff of the Imperial Department of Agriculture for the West Indies 137

The Preparation of High Grade Sugar-cane Syrup,

By A. E. Collens and F. H. S. Warneford, Government Laboratory for the West Indies 154

Liming as a means of Soil Amendment,

By F. Hardy, Chemist on the Staff of the Imperial Department of Agriculture for the West Indies 161

Studies in West Indian Soils. II.—The Soils of Montserrat, their Natural History and chief Physical Properties, and the relationship of these to the problem of Die-back on Lime Trees,

By F. Hardy, Chemist on the Staff of the Imperial Department of Agriculture for the West Indies 189

Growth and Correlation in Sea Island Cotton,

By T. G. Mason, M.A., Economic Botanist and Acting Assistant for Cotton Research, on the Staff of the Imperial Department of Agriculture for the West Indies 214

Report on the Prevalence of some Pests and Diseases of Crops in the West Indies during 1920

(Compiled from the Reports of the local Agricultural Officers) 239

THE ECOLOGICAL SIGNIFICANCE OF SOIL SHRINKAGE *

BY T. G. MASON, M.A., Sc.B. Agr.B.,

Botanist on the Staff of the Imperial Department of Agriculture for the West Indies.

Statement of The Problem.

A good general correlation was found by Sir Francis Watts [22] to exist in certain valleys of Dominica, between the percentage linear shrinkage of the soil on air drying and the condition of cacao rooted in it; relatively large shrinkages were in general accompanied by the failure of the cacao. It was primarily with the object of ascertaining the ecological significance of this relationship, and secondarily in the hope that some principle of wider application might emerge from the investigation, that the work reported in this paper was undertaken

Introduction.

The employment of soil shrinkage determinations as an index to soil texture, was initiated by Sir Francis Watts, while Government Chemist and Superintendent of Agriculture of the Leeward Islands. It was thought, Auchinleck [1] states, that by measuring the shrinkage upon drying experienced by masses of soil of similar plasticity, some approximate relative measure of the average size of the solid particles would be obtained; th t clay soils would show large and sandy soils small shrinkages. Subsequent investigation by Tempany [20] appeare l to indicate that the contraction on drying exhibited by any particular soil, depended directly on its content of colloidal clay, and that a simple means was thus provided of calculating the proximate

*Received for publication June 15, 1921.

content of colloidal clay. From this view-point it seems legitimate to infer that a high percentage of colloidal clay is directly inimical to the successful cultivation of cacao. Such an interpretation appears superficially to be in good accord with the heavy precipitation in Dominica, and the somewhat exacting water requirements of cacao, for a highly colloidal impermeable soil would evidently remain water-logged throughout periods of heavy rainfall, and would therefore be not only physiologically dry* as a result of inadequate ventilation, but might be distinctly toxic, owing to the presence of organic acids ‡ and the reducing potential capacity of the soil solution.

Inspection of Table I will show the nature of the relation established by Sir Francis Watts between the percentage linear shrinkage of the soil on air drying, and the condition of cacao trees growing in two valleys in Dominica. Shrinkage determinations were carried out both on the surface and the subsoils of several cacao fields. A report was then obtained from the manager as to the condition of the cacao growing on the fields which supplied the samples. It will be noted that where the shrinkage of the surface soil was greater than 10 per cent., the cacao was reported to be in poor condition; sample F was, however, exceptional in that respect. Numerical statements as to the condition of the trees were apparently not available. The correlation was nevertheless considered sufficently striking to render it desirable that further information as to the mechanism of soil shrinkage should be obtained. It should be emphasized that the limits of soil shrinkage above which cacao failed to thrive in these two valleys in Dominica might be sensibly different under another complex of aerial subterranean conditions. The presence of shade trees, for instance, might considerably modify the relationship. This aspect of the subject can evidently be more readily comprehended after consideration of the mechanism of soil shrinkage. Attention should be drawn, however, to the differences in amount of shrinkage exhibited by the surface and the subsoil. A marked tendency will be noted (Table I), particularly where the condition of the cacao was good, for the latter to exceed the former.

---

* The first effect of oxygen deprivation is an interference with the absorption of water by roots : cf. Livingston and Free [15] ; see also Howard [12] and Bergman [4].

‡ Salisbury [18] has recently pointed out, however, that even completely water-logged soils need not necessarily become more acid, though other attendant evils assert themselves, and cites Gillespie [10] who found that soils treated with excess of water may become less acid, though exhibiting an increased reducing capacity.

TABLE I.

Sample.	Shrinkage per cent.	Condition of cacao.
A. Surface soil	8	Cacao growing well.
Subsoil	12	
B. Surface soil	13	Cacao failing.
Subsoil	17	
C. Surface soil	12	Cacao very poor.
Subsoil	11	
D. Surface soil	9	Cacao doing well.
Subsoil	12	
E. Surface soil	10	Cacao growing well.
Subsoil	15	
F. Surface soil	13	Cacao fair.
Subsoil	17	
G. Surface soil	13	Cacao died.
Subsoil	11	
H. Surface soil	14	Cacao died.
Subsoil	17	
I. Surface soil	8	Good.
Subsoil	8	
J. Surface soil	12	Poor.
Subsoil	10	
K. Surface soil	10	Good.
Subsoil	10	
L. Surface soil	10	Good.
Subsoil	10	
M. Surface soil	10	Fair.
Subsoil	13	

Experimental.

With a view to ascertaining whether the failure of cacao to thrive on soils with relatively high shrinkages (cf. Table I) is to be ascribed to an intolerance of cacao to highly colloidal soils, or whether this interpretation of the results of soil shrinkage measurements requires modification, determinations were made of the soil moisture residues at permanent wilting (the wilting coefficient of Briggs and Shantz [5]), the percentages of moisture at the point of maximum plasticity, and the percentage linear shrinkage on air drying of a number of soils *.

It was considered that the problem could be most readily approached by comparing the percentage linear shrinkage of a number of soils with the estimations of their colloidality. Methods of ascertaining the degree of dispersion of the soil particles, (of Beaumont [3],) it is generally admitted, are lacking in any high measure of precision The soil moisture residue at permanent wilting has been shown by Briggs and Shantz [5] to be highly correlated both with the hygroscopic coefficient and the moisture equivalent, both of which are closely related to the degree of dispersion and the interior surface of the soil. It has accordingly been employed as one means of forming an approximate estimate of the colloidality of the soil. The wax-seal method of Briggs and Shantz [5], using maize plants (*Zea mays*) as biological indicators of soil moisture conditions was employed in these determinations. Particular precautions were taken to maintain the rates of transpiration low (cf Caldwell [6]). Direct sunlight was excluded, and air movement was reduced by canvas screens; the humidity of the aerial environment was increased during the forenoon by moistening the screens. Five cultures, each containing two plants, have been used for each determination.

The second method adopted in order to ascertain the colloidal content of the soil, was to determine the percentage of water imbibed by the soil at the point of maximum plasticity. The soil's hydration capacity is considered to be practically a function of the interior surface, and has accordingly been held to be an approximate index of the colloidal content. In order to bring the soil into this state, water is slowly added to the soil, which throughout is vigorously kneaded with the hands. As soon as it commences to adhere to the skin or to unglazed paper, the further addition of water is stopped; the soil is then allowed to dry, and throughout this period is kneaded. The moment at which it no longer adheres to the skin or to unglazed paper marks the point of maximum plasticity; at this stage the soil gels commence to pass into the sol state. Rohland [17] has argued that the moisture content of plastic clay is a measure of the colloids, because as soon as sufficient water is present to

---

*The mechanical effect of shrinkage on the root system has not been entertained as a possible explanation, owing to the nature and distribution of the rainfall in Dominica.

dissolve the coagulable colloids, a saturation point is reached and no more water can be added without the clay losing its stiffness.*

The method of measuring the linear shrinkage of the soil on air drying was similar to that introduced by Watts [22], and subsequently employed by Tempany [19]. The soil, on being brought to the point of maximum plasticity was moulded into the form of bricks, 3 by 1 by 1 inches in size, into which two fine pins were inserted at a distance of as nearly as possible 50 millimetres apart, the actual distance being found by careful measurement. The bricks were then set aside in a cool shady place to dry ; they were turned occasionally to promote even drying and to avoid warping ; as the process of drying proceeded, the distance between the pins was measured from time to time until the shrinkage ceased ; the results are stated in terms per cent. of the original distance between the pins. Five replicates were run for each determination.

The moisture residues at permanent wilting, the moisture contained by the soil at the point of maximum plasticity,† and the percentage linear shrinkages were measured in the following seven soils, four of which were obtained from Barbados, while three were artificially prepared :—

A. Yellow-red clay loam.
B. Rust red clay loam.
C. Black clay.
D. Grey clay.
E. 2 parts (volumetric) of black clay to 1 part sand.
F. 1 part „ „ „ 1 „ „
G. 1 „ „ „ „ 2 parts „

The natural soils A,B,C,D were air-dried, and the coarser particles removed by passing through a sieve of 2mm. mesh The preparation of the artificial soils E,F,G, was necessitated by the fact that all the Barbados' soils examined were of very nearly similar ' physiological heaviness,' as indicated by their moisture residues at permanent wilting, and by the fact that the importation of soils from the neighbouring islands was considered inadvisable.

The results of these determinations, together with the ratios between the percentages of moisture at the point of maximum plasticity, and the percentage linear shrinkages are presented in Table II.

Inspection of the table shows that a good general correlation exists between the soil moisture residues at permanent wilting and the percentage of moisture at the point of maximum plasticity. It is patent, on the other hand, that no such relationship exists between the latter and the linear shrinkages. It is manifest that if the linear shrinkage is even approximately proportional to the colloidal content of the soil,

*The soils were left for some days in a moist condition to ensure completion of imbibition.

†Expressed as percentages on the oven-dry basis.

it should be highly correlated both with the moisture residue at permanent wilting, and the percentage of water at the point of maximum plasticity. Auchinleck[1] has drawn attention to the lack of proportionality between shrinkage and the water content of the plastic brick. If they both depend, he says, on the percentage of clay present, as is assumed, the proportionality should be very exact. In a gel, the total contraction in volume on air-drying is doubtless very nearly proportional to its hydration capacity.*

In the soil, the conditions are naturally quite different. The modern view is that the soil is a system of mineral particles of all sizes, which are covered with a colloidal film, and that this film is relatively thicker the smaller the particles (cf. Beaumont, Keen [19]).

In the great masses of agricultural soils the particles are aggregated to form compound particles. Comber [7] conceives these aggregates as having large nuclei surrounded by particles which become smaller and smaller from the centre of the aggregate outwards, the clay ultimately imposing its 'emulsoid' nature on the whole aggregate, and on the whole soil in normal cases. The crumb, which is generally regarded as meaning a relatively large loose aggregate (cf. Hilgard [3]), is formed through the combination of these colloidal aggregates, though doubtless no sharp line can be drawn between the two. The crumb, of course, may be largely resolved into its component compound particles when the soil is kneaded in bringing it to the condition of maximum plasticity. The more firmly cemented compound particles, on the other hand, are disintegrated (peptisid deflocculated) with greater difficulty (e.g. through the agency of electrolytes, heating, the passage of an electric current). It is improbable that they are disintegrated to any marked degree in kneading the soil prior to the determination of the amount of shrinkage. Moreover, if the surface tension at the interphase between the particles and the soil solution is the factor which determines the agglomeration of the particles (cf. Free [8], Sharp[19]) it is possible that any disintegration which may occur in the process of kneading is merely temporary, and that as the plastic soil dries, reflocculation takes place. The distintegration into well defined aggregates may be observed, for instance, on immersing the air-dried brick in a relatively large volume of water.

On the assumption that the compound particles are not destroyed, at least permanently, in kneading the soil preparatory to shrinkage determinations, it is possible to frame a tentative hypothesis to explain the relatively small shrinkages exhibited by the two most colloidal soils A and B (Table II). At the point of maximum plasticity, the soil gels are regarded as saturated with water and ramifying through the brick. Water must also be present to some extent in the interstices between the particles,

*As a gel imbibes water it swells, but the volume gel + water is less than the original volume of the two components. Swelling, therefore, is accompanied by compression of the water, so that the increase in volume is not apparently a linear function of the water imbibed. The converse should also hold, viz. that shrinkage on drying is not directly proportional to the hydration capacity.

TABLE II.

Soil.	A.	B.	C.	D.	E.	F.	G.
(a) Soil moisture Residue at Permanent Wilting.	33·2 ± 0·33	31·3 ± 0·14	27·1 ± 1·07	25·0 ± 0·33	17·3 ± 0·45	16·4 ± 0·76	13·6 ± 0·73
(b) Moisture Content at Point of Maximum Plasticity.	48·2 ± 0·99	45·5 ± 0·14	43·9*	39·8 ± 0·10	35·4 ± 0·25	30·8 ± 0·14	24·0 ± 0·33
(c) Percentage Linear Shrinkage.	8·8 ± 0·16	8·2 ± 0·08	13·2 ± 0·21	11·8 ± 0·11	10·6 ± 0·22	7·6 ± 0·10	3·7 ± 0·18
Ratio $\frac{b}{c}$	5·48	5·55	3·33	3·37	3·34	4·05	6·49

* Only 3 obsrvations.

both aggregated and not aggregated. The hydration capacity as determined by the percentage of water at the point of maximum plasticity cannot, therefore, be exactly proportional to the interior surface. Three fairly well-defined stages may be distinguished in the progressive loss of moisture which accompanies shrinkage.

In the first the movement of water from the interior of the brick occurs as rapidly as it evaporates from the surface, the contraction in volume being proportional to the amount of water loss.

The second stage commences when the internal friction, due to the approach of the soil particles, both aggregated and not aggregated, becomes sufficiently pronounced to exert a retarding effect on the rate of contraction. Throughout this stage evaporation continues from the surface of the brick alone, for the whole is still completely permeated with water. The water of course passes into a state of tension as a result, on the one hand, of the steady pull due to evaporation, and, on the other hand, to the increasing resistance to further shrinkage opposed by the approach of the soil particles. Throughout this stage there is a gradual diminution in the rate of shrinkage in relation to the corresponding rate of water loss (cf. Tempany [20]). The second stage terminates when the tension becomes sufficiently pronounced to cause a rupture in the continuity of the water permeating the brick; air bubbles appear in the interstices, and consequently the tension ceases.

In the third stage the continuity of the water no longer exists, and, therefore, the shrinkage of the brick as a whole ceases. The evaporation of water continues, however, into the soil interstices.

It is patent that, in soils in which there occurs a marked aggregation of particles, the resistance to shrinkage will be relatively greater than where the colloids exist in a more diffused state.

From this it follows that, the rate of development of the critical tension at which the rupture of the stressed water of the brick occurs, will depend for a given colloid content, rate of evaporation, temperature, and tensile strength of soil solution, upon the degree of aggregation of the soil particles.

The portion of the total moisture contained in the plastic brick which is lost at the moment shrinkage ceases, must therefore be greater the more diffused the condition of the colloids. And since the amount of linear shrinkage is assumed to be proportional to the water lost through evaporation before contraction of the brick ceases*, it must follow that the shrinkage is greater the more diffused the colloids.

Moreover, where the aggregation of particles is considerable, and where the size of the interstices is accordingly large, the absence of resistance to the growth of air bubbles, when the water in the brick passes into a state of tension, will permit a rupture in the continuity of the water, and a consequent cessation of shrinkage, while the tension is still relatively small It can be

*The relationship between linear contraction and water loss is not of course strictly linear in character (cf. Tempany [20]).

readily realized, therefore, that shrinkage should be greater the more diffused the condition of the colloids. From these considerations it would appear that the diffusion of the colloids should be less in soils A and B than in either C or D (Table II); and though the former pair are more highly colloidal than the latter, they should at the same time be more permeable to water and air. It will be remembered that the soils A and B were described as a yellow-red and rust-red loam, respectively, their colour being due presumably to the presence of colloidal ferric oxide. This in itself is an index to good drainage conditions (cf. Hilgard [13]), for ferric oxide cannot long exist in soils under poor drainage conditions, owing to the reducing capacity of the soil solutions.

The permeabilities of the four natural soils were compared, however, by placing equal volumes of the air-dried soils in Buchner filters (2 cm. columns of soil), and noting the relative rates of water penetration by observing the time required for the percolation of a definite volume of water (15 c.c.) under a uniform head of water. The results are shown in Table III.

TABLE III.

Soil.	A.	B.	C.	D.
Time in seconds for percolation of 15 c.c. H_2O.	75	90	165	220

The method admittedly leaves much to be desired. Nevertheless, the differences are considered to be sufficiently pronounced to warrant the conclusions that the more colloidal soils, A and B, were distinctly more permeable to water than either C or D.

CONCLUSIONS.

It is concluded as a result of the experiments recorded in the preceding section of this paper, that the percentage linear shrinkages exhibited by a soil on air drying is not determined solely by the colloidality of the soil. The amount of shrinkage is conceived to be mainly controlled by two antagonistic factors: on the one hand, the degree of dispersion of the soil particles which determines the soil moisture content at the point of maximum plasticity, and on the other, the degree of aggregation of particles into compound grains, which decides the proportion of this moisture which is evaporated when shrinkage ceases. The greater the colloidality and the less the aggregation, the greater should be the contraction in volume on drying. Thus, for any two soils of similar imbibitional capacity (colloid content), the shrinkage is held to be roughly proportional to the flocculation of the colloids, and therefore to the soils' premeability to water.

From this point of view, the failure of cacao growing on soils exhibiting a linear shrinkage of more than 10 per cent. (Table I) is to be ascribed to the conditions liable to attend the diffused

condition of the colloids in such soils; among these conditions may be mentioned impermeability to water, insufficient oxygen for the roots and aerobic soil organisms, resistance to root penetration, and toxicity due to organic acids and the reducing capacity of the soil + water complex. Moreover, the tendency of the surface soil to exhibit smaller shrinkages than the subsoils (cf. Table I) may be explained on the assumption that the aggregation of colloids is greater in the upper regions of the soil.

Measurements of soil shrinkage alone, it is evident, must be very misleading when employed to indicate either the degree of dispersion, or the state of aggregation of the soil particles. It is possible to conceive, for instance, that two soils may exhibit similar shrinkages, but may vary widely both in their colloidality and their permeability to water. Consider two such soils, each with a linear shrinkage of 10 per cent., the one containing 40 per cent. and the other 30 per cent. of water at the point of maximum plasticity. The latter, it will be patent, though the less colloidal, may still be the more impermeable of the two, owing to the diffused condition of its colloids. A statement of the ratios between the water content at the point of maximum plasticity and the percentage shrinkage may be found, however, on further investigation, to be of considerable value as a means of comparing the degree of aggregation of particles in highly colloidal soils. Consideration of these ratios* in the case of the four soils A, B, C, and D, is particularly instructive in this connexion. The first two, it will be remembered (Table II), though more colloidal than either C or D, have been shown to be distinctly more permeable to water.

The need † of a method of readily ascertaining the aggregation of soil particles is very great; for as Russell [16] says, 'the significant units in the soil that determine its intrinsic properties are the compound particles made up of the ultimate mineral particles.' In regions where periods of torrential rain alternate with spells of drought, the existence of adequate aeration during the former, and of physiologically available water during the latter, are the prime conditions determining whether a particular soil is suitable, or the reverse, for the growth of any single kind of plant. To meet these requirements, the soil should possess as high a water-retaining capacity as is compatible with proper drainage and ventilation. The higher its colloidality and the greater the aggregation of its particles into compound grains, the more nearly it fulfils these conditions.

---

* It would be more accurate to express this as the ratio of $\frac{\text{No. of c.c. of water in}}{\text{No. of c.c. of shrinkage of}}$ a brick of 100 c.c. at the point of maximum plasticity.

†Keen [14] cites some work of Mitscherlich, who has approached this problem by attempting to ascertain the total interior surface by measuring the soil's hygroscopicity over 10 per cent. sulphuric acid in a vacuum desiccator, and the total outer surface of the particles and aggregates by replacing the acid by a liquid of high molecular weight, which is supposed to condense only on the outer surface of the compound particles. For ecological purposes, the use of the hygroscopic coefficient as an index to the total surface, and the determination of the diffusion of colloids by sedimentation (cf. Hoagland and Martin [11]) would probably afford a more reliable index to soil texture than any method at present in general use.

A diffused condition of the ultimate particles brings inits train a compact, impermeable, badly aerated soil ; such soils are unfortunately very common at present in the West Indies. Earle [3], for instance, has recently pointed out that root diseases of the sugar-cane, in common with other diseases due to facultative parasites, are as a rule best controlled by improved cultural methods, the employment of properly balanced fertilizers, attention to drainage, and keeping the soil *porus* and *open*. William's work [23] on the Froghopper blight of sugar-cane in Trinidad is of considerable interest in this connexion. The blight was found to be worse on heavy sour soils than on light, well aerated, well limed soils 'The acidity,' he points out', 'is probably more an indication of the *physical condition* that has brought it about: all the acid soils were heavier and more impervious than the alkaline or neutral undamaged soils.' The attacks of Thrips on Cacao are apparently in a large measure to be traced to a similar source (cf. Ballou [2] ; see, however, Urich[21]).

The diffused condition of colloids and the resulting diminution in permeability are apparently associated with the removal of particular agglomerating ions from the soil. Sharp[19], for instance, has shown that a soil may be made considerably more impermeable by the addition of certain sodium salts and subsequent leaching of the soil ; calcium and magnesium appear in the percolate in considerable quantities, the sodium being retained by the soil. The diffusion of colloids is regarded by Sharp as mainly due to the formation of new silicates rather than to the disintegration of the colloidal aggregates. Hoagland and Martin [14] have also recently recorded some work in which it is shown that a very good general correlation exists between the concentration of electrolytes in the soil solution and the diffusion of soil colloids, and that both undergo very marked variations coincidently with seasonal changes and crop growth. That the removal of solutes from the soil solution by the plant in itself results in a diffusion of colloids, is a conception of paramount importance. It cannot be too strongly urged that the plant and its whole environment, both aerial and subterranean, constitute a single system, the component parts of which continually act and react one on the other.

Summary.

(1) Attention is drawn to a correlation established by Sir Francis Watts between the condition of the cacao grown in certain valleys of Dominica and the percentage linear shrinkage of the soil on air drying ; the cacao failing to thrive where the shrinkage exceeded 10 per cent.

(2) An attempt to elucidate the significance of this relationship was made by comparing the percentage shrinkage of a number of soils with their moisture residues at permanent wilting (the wilting coefficient of Briggs and Shantz), and the percentage of moisture in the soil at the point of maximum plasticity.

(3) It was concluded that the amount of shrinkage exhibited by any soil on air drying is not determined solely by its

colloidality or degree of dispersion, but is dependent also on the degree of aggregation of the particles into compound grains, the greater the dispersion and the less the aggregation, the greater the shrinkage for a given temperature, rate of evaporation, etc.

(4) The poor condition of the cacao, under the particular complex of environmental condition of these valleys, when rooted in soils whose linear shrinkage exceeded 10 per cent., has been provisionally ascribed, therefore, to the degree of diffusion of colloids in such soils, and not merely to their colloidal content. Diffusion of soil colloids, it is emphasized, renders the soil impermeable to water and consequently poorly aerated, especially under conditions of prolonged and heavy rainfall.

Literature.

(1) Auchinleck, G. The measurement of shrinkage in soils and its application in Agriculture. *West Indian Bulletin*, Vol. XII, p. 50-61, 1912.

(2) Ballou, H. A. Observations on Insect Pests in Grenada *Bull. of Entomological Research*, Vol. VI, Pt. II, pp. 173-81, 1915.

(3) Beaumont, A. B. Studies in the Reversibility of the Colloidal Conditions of soils. Cornell Univ. Exp. Sta. *Memoir*, 21, 1919.

(4) Bergman, H. F. The Relation of Aeration to the Growth and Activity of Roots, and Its Influence on the Ecesis of Plants in Swamps. *Annals of Botany*, Vol. XXXIV, No. CXXXII, pp. 13-33, 1920.

(5) Briggs, L. J. and Shantz, H. L. The wilting Coefficient for Different Plants and Its Indirect Determination. U. S. Dept. of Agric. Bureau of Plant Ind. *Bull.* 230, 1912.

(6) Caldwell, J. S. The Relation of Environmental Conditions to the Phenomenon of Permanent Wilting in Plants. *Physiological Researches*, Vol. I, No. 1, pp. 1-56, 1913

(7) Comber, N. M. The Flocculation of Soils. *Jour. Agric. Sci.* Vol. X, Part 4, pp. 425-30, 1920.

(8) Free, E. E. Studies in Soil Physics I. *Plant World*, Vol. 14, No. 2, pp. 29-39, 1911.

(9) Earle, F. S. Sugar-Cane Root Disease. *Jour. Dept. Agric.* of Porto Rico, Vol. IV, No. 1, 1920.

(10) Gillespie, L. J. Reduction Potentials of Bacterial Cultures and Soils. *Soil Science*, 9, pp. 199-215, 1920.

(11) Hoagland, D. R and Martin, J. C. The Effect of Season and Crop Growth on the Physical State of the Soil. *Jour. Agric. Res.* Vol. XX, No. 5, pp. 397-404, 1920.

(12) Howard, A. 'Soil Aeration in Agriculture,' Agric. Res. Int. Pusa. *Bull.* 61, pp. 1-121, 1916.

(13) Hilgard, E. W. Soils, p. 109, p. 284, 1918.

(14) Keen, B. A. The Relations Existing Between the Soil and its Water. *Jour. Agri. Sci.* Vol. X, Part 1, p. 44-71, 1920.

(15) Livingston, B. E. and Free, E. E. The Effect of Defficient Soil Oxygen on the Roots of Higher Plants.

(16) Russell, E. J. Soil Conditions and Plant Growth, p. 141 London.

(17) Rholand, P. See Searle A. B.—Clay and Clay Products, p. 133, Third Report on Colloid Chemistry and its General and Industrial Applications. Department of Scientific and Industrial Res, London

(18) Salisbury, E. J. The Significance of the Calcicolous Habit. *Jour. Ecology.* Vol. VIII, No. 3, pp. 202-15 1920.

(19) Sharp, L. T. Fundamental Interrelationships between certain Soluble Salts and oil Colloids. University of California *Publications in Agric. Sci.* Vol. I, No. 10, p. 291-339, 1916.

(20) Tempany, H. A. The Shrinkage of Soils. *Jour. Agric. Sci.*, Vol. VIII, pp. 312-32, 1917, and *West Indian Bulletin*, Vol. XVII, No. 2, p. 107-18.

(21) Urich, F. W. Thrips, Black Ants and other Insect Pests of Cacao in Grenada with a Note on Coco-nut Disease. Trinidad 1918.

(22) Watts, F., See Auchinleck G. (1).

(23) Williams, C. B. Report on Froghopper Blight of Sugar-Cane in Trinidad. *Memoirs* of the Department of Agriculture, Trinidad and Tobago. No 1 1921.

THE PHYSIOLOGICAL HUMIDITY OF THE SOIL AND ITS DIRECT DETERMINATION.*

BY T. G. MASON, M.A. Sc.B. Agr B.

Botanist on the Staff of the Imperial Department of Agriculture for the West Indies.

Statement of the Problem.

This investigation was undertaken with a view to developing a simple method for the direct determination of the soil's humidity in as far as this is directly related to the growth and maintenance of the life of the plant. The elaboration of such a method is prerequisite to the investigation of a large number of problems of pressing economic importance in the tropics. For instance—

(i) the effects of different forms of mulching, cultivation and manuring on the conservation of soil moisture;

*Received for publication, June 15, 1921.

(ii) the premature shedding of cotton bolls and citrus fruits;

(iii) the relation between the aridity of the environment as a whole (aerial and subterranean), and the characters of the lint of cotton;

(iv) the susceptibility of the plant to insect and fungous attacks under varying conditions of environmental aridity.

Introduction.

It is almost universally recognized that a bald statement of the total percentage of moisture in a soil conveys no information as to the soil's ability to supply moisture to the roots of plants. Sachs [71] was apparently the first to recognize that considerable variations in moisture content exist among different types of soils at the onset of wilting. His investigations in this field were confined to tobacco plants, which were grown in three different types of soils—a vegetable mould, a loam, and a quartz sand. It was found that wilting occurred while the soils contanied 12·3, 8·0, and 1·5 per cent. of water, respectively. Subsequent investigation (Gain [11], Hedgcock [2], Clements [7]) on the moisture residue in the soil corresponding to the onset of wilting of plants, appeared to indicate that some species were able to reduce the moisture content of the soil to a much lower level than others, and consequently, that the moisture available for growth was a function not only of the nature of the soil and its moisture content, but also of the species of plant. This opinion, it would appear, is still widely prevalent among many practical agronomists, and has sometimes been considered an important factor in determining the degree of drought-resistance exhibited by different species of plants. Briggs and Shantz [5], however, who have published comparatively recently, the results of an extensive series of observations, in which many different types of soils were employed, and more than a hundred different kinds of plants, have come to conclusions which stand in strong contrast to those of earlier workers in this field. By taking many precautions which had not been previously observed, they were able to demonstrate that the variations exhibited by different plants in their ability to reduce the soil moisture before the onset of permanent wilting was much less than had heretofore been supposed, and that the differences between crop plants in this respect was so slight as to be without practical significance in the selection of crops for semi-arid regions The slight differences which they did observe in the soil moisture residues, at the time of permanent wilting of different species of plants, were largely due, they considered, not to the ability of one variety to exert a greater pull than another on the soil water, but to a more perfect root distribution. The moisture content of the soil corresponding to the permanent wilting of the plant, expressed as a percentage of the dry weight, was designated the wilting coefficient of the soil. By permanent wilting is implied, that stage of progressive wilting from which the leaves fail to recover their turgidity within a period of twenty-four hours, when the plants are exposed to a practically water-saturated atmosphere in the dark. It was concluded that the

soil moisture residue at the time of permanent wilting was not influenced to any appreciable extent by the evaporation conditions of the air, and that a considerable change in light intensity was without any marked effect. Caldwell, however, has demonstrated that their conclusions in this respect must be radically modified, for the soil moisture residue at the onset of permanent wilting has been shown to vary in a regular and predictable manner with the evaporating power of the air. It is evident, as a result of Caldwell's investigations, that it is only when the plant is allowed to wilt in a shaded moist chamber, that the wilting coefficient of Briggs and Shantz assumes the aspect of a soil constant. The physiological classification of the soil's moisture, which results from the studies of Briggs and Shantz, has been summarized by Alway, as follows:—

1. *Water available for growth.*—The difference between the total water content and the wilting coefficient.

2. *Portion of the available water not available for growth, but available for the maintenance of life.*—The difference between the wilting coefficient and the moisture of the soil in equilibrium with the air.

3. *Non-available water.*—The moisture content of the soil when in equilibrium with the air, or, in other words, the water content of the air-dry soil. No distinction, however, as Alway points out, was drawn between the physiological importance of the portion of the water between the wilting coefficient and the hygroscopic coefficient*, and that of the portion between the hygroscopic coefficient and the air-dry state. They did, however, make a comparison between the soil moisture content at the wilting point and at the death point as criteria for comparing plants in their relation to soil moisture. The average error in determining the wilting coefficient was found to be considerably less than that accompanying the determination of the moisture content corresponding to the death point. Moreover, the wilting coefficient was found to be practically independent of the kind of plant used as an indicator, whereas the death point varied with the plant used. Alway [1], too, in the course of his investigations on the relation of the non available water of the soil to the hygroscopic coefficient, has observed that some desert legumes remained alive after the water content had fallen slightly, but distinctly, below the hygroscopic coefficient; while wheat, milo, beans and maize plants showed but little difference in their ability to exhaust the soil moisture before the death of the plants. Alway has therefore felt justified in employing the hygroscopic coefficient as a datum for comparing the amount of physiologically available water in different soils. The percentage of water in excess of the hygroscopic coefficient has been designated 'free water.' The use of the hygroscopic coefficient as a datum for estimating the reservoir of available water in the soil, possesses the advantage that it does not overlook the importance,

* The hygroscopic coefficient expresses the percentage of moisture contained in a soil, which in an air-dry condition is brought into a saturated atmosphere, kept at constant temperature, and allowed to remain until in approximate equilibrium with this atmosphere. It provides apparently a simple means of forming an approximate estimate of the degree of dispersion or interior surface of the soil.

for the maintenance of life, of the portion of the soil moisture between the wilting coefficient and the hygroscopic coefficient; it can, in addition, be readily determined with comparative facility. On the other hand, it is apparently merely an index to the interior surface of the soil; and though it is unquestionably often very markedly correlated with the soil moisture residue at permanent wilting, it does not appear to rest on any very definite physiological basis; and moreover, is not directly related to the rate of water migration through the soil, a factor of evident moment in determining the rate at which water may be supplied to plant roots.

It will be recognized that a statement of the growth-water (the difference between the total percentage of moisture in a soil and the wilting coefficient of Briggs and Shantz), or of the amount of free water (the difference between the total percentage of moisture in a soil and the hygroscopic coefficient), though valuable for purposes of comparing the reservoir of physiologically available moisture in soils, affords no criterion to the intensity of the forces with which a soil withholds moisture from a plants' roots (i.e., the back-pull due to the soil). Thus, Alway[1] points out that corn plants may be dying in a soil with a hygroscopic coefficient of 15 and containing 3 per cent. of free water, while plants of the same kind in a soil with a hygroscopic coefficient of 0 5, may be very vigorous with 1 per cent. of free water. Such a condition, one persumes, is to be explained on the assumption that the forces with which the former soil retains its moisture (with 3 per cent. of '(free-water)' are greater than those of the latter (with 1 per cent. of 'free-water'); or to state the case in another way, that the hygroscopic and capillary forces of the former soil with 18 per cent. of water are less nearly satisfied than those of the latter with 1·5 per cent. of moisture This aspect of the subject is apparently somewhat analogous to the distinction which is drawn between the total acidity and the hydrogen-ion concentration of physiological solutions. A mere statement of the total acidity offers no information as to the intensity of the acidity, which alone is of direct biological significance; similarly a bald statement of the amount of growth —or free water—is bereft of physiological meaning unless accompanied by a knowledge of the wilting or of the hygroscopic coefficient as the case may be. Alway and McDole[2], [3] have accordingly employed the ratio of the total moisture content to the hygroscopic coefficient as an index to the physiological humidity of the soil. Thus, a ratio of 1·7, for example might indicate a soil with a hygroscopic coefficient of 10 and a total moisture content of 17 per cent. or it might denote one with a hygroscopic coefficient of 5 containing 8 5 per cent. of moisture. Of a somewhat similar nature is the coefficient of soil humidity proposed by Crump [8], which is defined as the ratio of the total percen age of moisture* to the humus content. It is naturally only of value in peats and soils containing large quantities of organic colloids. It would apparently be equally logical to express the physiological humidity of the soil as the

* The moisture content is determined by measuring the loss of water after thorough air drying at 15°C., and the humus content by the loss in weight when the peat, previously heated at 100°C., is ignited to a dull red heat.

ratio of the total moisture content to the moisture equivalent†, or to any other index to the colloid content or interior surface of the soil. Methods of this nature, which aim at expressing the ratio of the total moisture to the interior surface of the soil are clearly of considerable value, but are not without certain objections. In the first place, they evidently proceed on the assumption that the force with which the soil retains its moisture is a linear function of its moisture content; an assumption which is unjustified in view of Shull's [18] work on surface forces in soils. In the second place, no account is taken of the differences which exist in facility of water transmission among different soils, which is a function not only of the colloidal nature of the soil but of a number of soil properties which cannot yet be readily characterized. Recognizing the difficulties involved in obtaining an expression for comparing the relative moistness of soils by the integration of such static features, Pulling and Livingston [15] have approached the problem from the dynamic point of view, and have elaborated a method of measuring directly the water-supplying power of the soil, somewhat in the same way as the evaporating power of the air is now determined by direct methods, without recourse to the integration of such features as air temperature, moisture and movement. The method consisted in observing the rate at which a solution of known concentration in a thistle-osmometer withdrew water from the soil. The water-attracting forces exerted by the solution were opposed by the surface forces retaining the moisture in the soil and the osmotic pressure of the soil solution. The difficulties involved in maintaining adequate contact between the adsorbing membrane of the osmometer and the soil, rendered the method more suitable for laboratory use than for work in the field. Recently another method has been proposed by Livingston and Koketsu [13] in which advantage is taken of the marked water-attracting forces of dry porous porcelain. Artificial roots of porous porcelain, for which the term soil-points is temporarily employed, are placed in the soil for a definite period, and the weight of water imbibed is employed as an index to the water-supplying power of the soil. With a view to ascertaining whether the assumptions on which the proposed method had been based were legitimate or not, the water-supplying powers of a number of soils of varying texture were determined by the porcelain soil-points at the onset of permanent wilting. At this critical stage, all soils, irrespective of their textures, are to be considered as similar in their ability to supply water to the roots, and should, therefore, if the assumptions on which the method were based were correct, be alike, in their capacity to supply water to the artificial roots employed. For a large range of soils studied the soil-points registered practically the same water-supplying power. It was with a view to testing further this method, possibly simplifying it and introducing a modification of detail, so rendering it available for the analysis of ecological and agricultural problems, that the present investigation was undertaken.

† The moisture equivalent of a soil is the percentage of water left in the soil after centrifuging for a certain time under a force of 1,000 gravities, a force about equal to one atmosphere. Sharp and Waynick (*Soil Science*, 4,6,463-69, 1917,) have employed it as an index to the interior surfaces of soils.

Method.

The principle of the method adopted was similar to that of Livingston and Koketsu. In place, however, of porous porcelain soil-points, hard-leaded writing pencils * were employed a the suggestion of Dr. Livingston. The imbibitional forces of the wood have been found to be satisfactory for this purpose. A very nearly constant absorbing area was readily obtainable by using an ordinary mechanical pencil sharpener; the rest of the surface except the unsharpened end, which was sealed with paraffin wax, remaining water proofed by the varnish of the pencil. A number of these pencil soil-points, after standardization and 'sharpening', were weighed and inserted in the soil for a definite period, the hard lead of the pencil assisting the penetration of the conical absorbing surface. As the absorbing surface came to rest, contact between it and the soil was attained in a manner somewhat similar to that between a growing root and the surrounding soil. In both cases the soil immediately about the absorbing surface becomes somewhat compressed. It is evidently of moment that the compression of the soil should approximate as closely as possible to that due to the root †, and that it should not differ from one determination to another. Care was accordingly exercised to insert the soil-points slowly in to the soil. If this precaution is neglected, the rate of water transmission may be appreciably accelerated. At the termination of a definite period, the wooden soil-points are withdrawn, and, after the careful removal of adhering soil by a cloth, reweighed. The gain in weight is taken to be an index to the water supplying power of the soil. A celluloid case to prevent water loss while the soil points are being transported between soil and balance has been found unnecessary with the laboratory conditions under which this work was carried out, but naturally would be essential for field observations.

As soon as contact is established between the soil water and the absorbing surface of the soil-point, a movement of water is initiated. The soil region in immediate contact with the absorbing surface is thereby partially dried, and its attraction for water consequently increased. Meanwhile the active area of the soil-point is correspondingly moistened, and its attraction for water accordingly diminished. The rate of reduction in the water-attracting forces of the soil-point is naturally more rapid the greater the humidity of the soil. By inserting the soil points for only a relatively short period in the soil, this factor has been found to offer no particular difficulty.

The results accruing from the tendency of the soil in the region of the soil-point to become progressively dried are more difficult to gauge. The first effect of this desiccation is clearly to augument the water attracting forces of this region of the soil, and thus occasion a movement of water to replace that absorbed by the soil-point. If, however, for the period of a test, the migration of water through the soil occurs at approximately

* Koh-i-noor. 6.H. Made by L. and C. Hardtmuth. Vienna.

† It seems desirable that the angle of the absorbing cone should be small,

the same speed as that at which it is removed by the soil-point, the rate of water movement from the soil into the soil-point remains nearly uniform during this period. Assuming then that the rate of water movement does remain uniform throughout the period occupied by the test, and that the two major factors on which the relative rates of movement from soil to soil-point at different soil moisture contents depend are, firstly, the relative ratios between the water-attracting forces of the soil and the soil-point, respectively; and secondly, the resistance opposed by the soil to water movement, the results attending the use of soil-points whose water-attracting forces are greatly in excess of those of the root may be briefly traced. It will be immaterial what moisture contents are assumed, but for convenience, the percentages of water corresponding to the moisture equivalent and the wilting coefficient of Briggs and Shantz will be considered. At the former the moisture is retained by the soil with a pressure of approximately one atmosphere, and in the latter, according to Shull [18], with a force of about four atmospheres. The ratio between the water-attracting forces of the soil at these two moisture contents and the absorbing surface of the soil point are 4 and 1, respectively, irrespective of the water-attracting forces of the soil-point; and, since the soil feature to be measured is purely a relative conception, the magnitude of the water-attracting forces of the soil-point should be immaterial. But by assumption, the relative rates of moisture movement from soil to soil-point at different moisture contents are also controlled by the resistance to water movement opposed by the soil. Now this resistance at relatively low moisture contents, when the soil water exists entirely as water of imbibition, must be extremely large, and, moreover, should increase more rapidly than in a soil of relatively high moisture content, for a given augmentation in the water-attracting forces of the soil-point may be of considerable importance, and should approximate as closely as possible to those of the plant root. If greatly in excess, the water supplying power indicated by the soil-point at high moisture contents, as compared to that at low contents, may be much greater than if a soil-point with water-attracting forces approximating more closely those of the root had been employed. One is here confronted with the difficulty that water-attracting forces of the roots are not only very variable, fluctuating in the course of a single day with the evaporating power of the air, but are also comparatively small; according to Shull, the pressure with which the soil holds its moisture at the onset of permanent wilting is only about four atmospheres. It seems improbable that the water-attracting forces of the root are ever greatly in excess of this.

It will be patent though, that where the water-attracting forces of the soil-point are as small as this, that an inconveniently long period would be required to carry out a test. It was therefore decided that the most satisfactory solution would be to use the soil-points while in moisture equilibrium with the air. The unvarnished ends were accordingly water-proofed with paraffin wax, and the soil-points used as required. After a test had been carried out, the absorbing end was cut away for about a quarter of an inch and then sealed. Before resharpening for

a second test, the parafin wax seal was removed with a knife. In this way it was found that no sensible error was introduced on using the soil points a second or even a third time.

The Time period Required for A Test.

The following experiments were undertaken with a view to ascertaining the most suitable time-period for a test of the water-supplying power under varying soil moisture conditions. A black clay was air dried and passed through a 2 mm. sieve. After thorough mixing, it was moistened by the addition of varying amounts of water and placed in a metal container 30 × 25 × 25 cm. In order to ensure an approximately uniform degree of compression (packing) in the moistened soils, the container was repeatedly tapped on the ground until no further reduction in volume could be observed. In the case of the soils of higher moisture content (above 36·4 per cent., Table I.) it was found impossible to bring them to their final moisture content before insertion in the container without undue adhesion occurring between the soil particles. These soils were accordingly

Table I.

Weight of water (hundredths of a gram) absorbed by two Soil-Points from a Black Clay Soil.

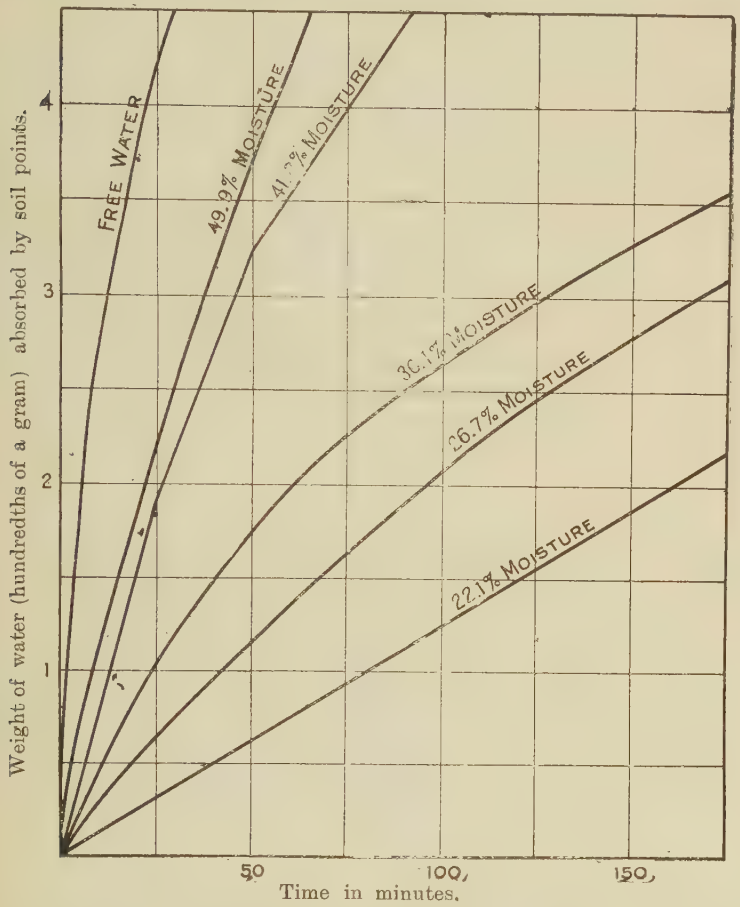
Time in minutes.	Percentage Moisture in Soil (on dry weight basis).					
	22·1	26·7	35·7	36·4	41·8	9·49
50			1·9	2·0	3·2	3·7
75			2·1	2·4	3·9	5·0
100		2·1	2·2	2·9	5·6	6·5
125			2·9	3·0	5·5	6·6
150	1·4					
200		3·3	3·7	3·5	9·3	7·8
300	3·7	4·6				
400	4·5	5·4				
600	5·5					

Table II.

Weight of water (hundredths of a gram) absorbed by two Soil-points from Free Water.

Time in minutes	5	10	15	20	30
Weight of water	1·5	3·0	3·2	4·0	4·4

brought to their full water content after insertion in the container by moistening the surface as uniformly as possible, and leaving for a period of four days to ensure adequate moisture distribution. In order to prevent evaporation, the surface was sealed with paraffined paper. The soil-points were weighed two at a time, and inserted in the soil to a depth of approximately 5 inches. On withdrawal from the soil, adhering particles were carefully removed with a fine cloth, and the gain in weight determined by reweighing.*



In Table I the results of a series of determinations carried out on the soil at six different moisture contents (expressed gravimetrically on the oven dry basis) are presented. Each result represents the mean of two observations, and for each observation two soil points were employed. A result therefore involved the use of four soil-points. The results are expressed

* The gain in weight due to the adhesiveness in the soil was determined by plunging the soil-point into the soil and instantly removing; it was not found to introduce any appreciable error.

as the weight of water in hundredths of a gram imbibed in a definite period. The degree of accuracy obtainable by the use of only four soil-pointsis admittedly small, but is sufficient to permit an estimate to be formed of the most suitable time-period of insertion for a test of the water-supplying power of the soil. For the purposes of reference and comparison, the rate of water absorption by the soil-points from free water are recorded in Table II. The absorbing area was placed just beneath the surface of the water. Each result in this case represents the mean of four observations involving the use of eight soil points.

The results recorded in Tables I and II are reproduced graphically in Fig. 1; but only those fractions of the curves are given which are requisite for an estimate to be formed of the time-period throughout which the rate of water absorption remained uniform. It will be observed that the rate of water movement remained almost constant for a period of thirty minutes at all the soil moisture contents employed in the experiment. At the lower moisture contents a much longer period may be employed, as the rate of absorption remains approximately constant for a considerable period. It will be evident that by making two tests, one of thirty minutes and another of three hours, the water-supplying power can be ascertained over a wide range of moisture contents. Where merely comparative results are wanted, the time-period loses much of its importance.

The Water-Supplying Power of the Soil at Permanent Wilting.

Since the method under investigation purposes to give an index to soil moisture conditions in as far as these influence the plant, it is necessary to adopt some critical physiological state of the plant, which is related to its soil moisture supply, and to determine the water-supplying power of a number of soils of varying texture, while the plants are in this critical condition. Permanent wilting is the most easily recognizable stage in progressive wilting fulfilling this condition, and has accordingly been employed in these studies. Seven different soils were used, four of which were obtained from different parts of the island of Barbados, while three were artificially prepared.

A. A yellow-red clay loam.
B. Rust-red clay loam
C. A black clay.
D. A grey clay.
E. 2 parts (volumetric) of black clay to 1 part sand.
F. 1 part „ „ „ „ „ 1 „ „
G. 1 „ „ „ „ „ „ 2 parts „

The natural soils A, B, C, D, were air-dried, and the coarser articles removed by passing through a sieve of 2 mm. mesh.

The preparation of the artificial soils was necessitated by the fact that all the Barbados soils examined were of nearly similar physiological heaviness, as indicated by the wilting coefficient of

Briggs and Shantz, and the fact that the importation of soils from the neighbouring islands was considered inadvisable. The wax seal method of Briggs and Shantz [5], using maize plants (*Zea mays*) as biological indicators of soil moisture conditions, was employed. Particular precautions were exercised to keep the rates of transpiration low. Direct sunlight was excluded, and air movement reduced by canvas screens; the humidity of the aerial environment was also artificially raised during the forenoon by moistening the screens. The selection of corn as an indicator was possibly unfortunate, owing to genetic heterogeneity and the difficulty of detecting the first stages of permanent wilting. Five cultures, each containing two plants, were employed for each soil. Each culture was placed in an approximately saturated atmosphere for twenty-four hours, as soon as the plants reached the permanent wilting stage, and if recovery occurred the culture was discarded. The water-supplying powers of the soils were then ascertained by means of the pencil soil-points, a period of three hours being used for each test. The percentage of moisture in each culture was next ascertained; the error introduced into the latter determination through the removal of water by the soil-points was of course quite negligible. The results are presented in Table III. The water-supplying powers of the soils have been recorded as the weight of water, in hundredths of a gram imbibed in a three hour period by two soil-points; fifteen tests were made for each soil, three in each culture. It will be recognized that the soils were alike, in their ability to supply water to the plant's roots as indicated by the loss of turgor and wilting of the plants,* and should, therefore, since the method aspires to measure the physiological humidity of the soil,† register by the soil-points similar values for their water-supplying powers. Reference to Table III shows that the values obtained ranged from 2·40 to 3·23, and that for the natural soils, A, B, C, and D, it ranged from 2·95 to 3·23. It will be patent, therefore, that the values registered by the soil-points are not identical, for the soils exhibited small though statistically significant differences in this respect. The total range, however, for the seven soils is only 0·83, whereas the range of water-supplying power of the soil at the moment of permanent wilting and of free water is approximately 47 (50‡-3). It will thus be seen that the differences in the water-supplying powers exhibited by the seven soils at permanent wilting are negligible in comparison with the total range of water-supplying power liable to be encountered by the roots. The soil moisture residues at permanent wilting it will be noted, varies from 13·6 to 33·2 per cent. Inspection of Table III also shows that, though appreciable variations are exhibited by both soil moisture residues at permanent wilting and water-supplying powers between the cultures of some of the soils, yet the two are only slightly correlated. It will be evident

* It should be noted that the soil moisture residues at permanent wilting will in general tend to be too low; this is due the difficulty involved in detecting the *onset* of permanent wilting.

† Only of course in non-toxic, non-saline, and thoroughly aerated soils.

‡ Calculated to a three-hour period. See Table III.

that any lack of uniformity in soil compression (packing) may make the various cultures of a single soil show differences in their moisture residues at permanent wilting On the other hand, as Dr. Livingston, points out (in lit.), 'with the same evaporation conditions, and with the same kind, age, size, etc., of plant, a given phase of wilting should always correspond to a definite water-supplying power of the soil.'

The Water Supplying Power of the Soil at the point of Maximum Plasticity.

It was deemed desirable to ascertain the water-supplying powers of the soils at the time the plants were in some other critical condition depending on their soil water-supply, in addition to that of permanent wilting. Unfortunately there are great difficulties involved in the recognition of any critical stage in the progressive loss of turgor which precedes permanent wilting. This object might have been achieved if it had been possible to bring the soil into any definite moisture condition bearing a constant relation to the wilting coefficient of Briggs and Shanz Inasmuch, however, as the latter can no longer be consid red a soil constant, it will be evident that this solution of the problem is out of the question. It was therefore decided to bring the soils into some state, which was a function only of its interior surface. The soil moisture content at the point of maximum plasticity appeared to approximate this condition as closely as any other. According to Rohland[16], the water of imbibition of the soil in this state is a measure of the collodial content of clays; the condition of maximum plasticity apparently marks the point of saturation of the soil gels. In order to bring the soil* into this state, water is gradually added and the soil thoroughly worked. As soon as it commences to adhere to the skin or to unglazed paper the addition of water is stopped; the soil is then allowed to dry, and throughout this period is kneaded by the hands The moment at which it no longer adheres to the skin or to unglazed paper marks the point of maximum plasticity; at this stage the gels, it seems, commence to pass into the soil condition. The soil-points were allowed to remain in the plastic soil for a period of thirty minutes; the results, however, which are shown in Table IV have been calculated to a three hour period (in each case). Five samples of each soil were prepared *independently* and placed in glass tumblers, which were then sealed with paraffined paper. It will be observed that the water of imbibition varied from 24·0 to 48·2; and that the maximum error of the mean of five samples is less than 2 per cent. The water-supplying powers, though agreeing closely in soils B, C, D, and F, show a range of 7·0 between soils A and E. It will also be seen that the water-supplying power of the soil at the time of permanent wilting is only about 21 per cent. of that at maximum plasticity.

---

* The soils were left for some days in a moist condition to permit the colloids to imbibe water. (c f. Beaumont, A. B., Memoirs, Cornell University Agricultural Expt. Station, 21, 1919.)

Discussion.

(a) The existence of a critical soil moisture content at which the plant attains its optimum development has received a certain amount of attention in the past. Free[10] has suggested that this optimum water content for the plant may correspond to the critical water content at which the soil exhibits its most favourable physical condition. In this connexion the work of Fowler and Lipman[9] on the optimum soil moisture conditions for young lemon trees on a loam soil is of interest. It was found that the soil moisture percentages within which the young trees made satisfactory growth was, relatively speaking, a wide one; but it is emphasized that it does not follow that the same wide range of moisture percentages would be similarly effective as regards fruit production. It is also of interest to note that the danger to the young trees was found to be greater from too much than from too little moisture in the soil. It must be remembered that the question as to whether there exists an annual optimum water-supplying power of the soil has never been investigated; a mere statement as to a particular range of soil moisture contents outside of which the plant fails to make satisfactory growth contributes very little to its solution unless such factors as soil aeration, physiological balance in soil solution, evaporating power of air, etc., are rigidly under control. In regions where irrigation is not practised, and where a well defined wet season occurs, considerable damage to cultivated plants is liable to result. It will be readily conceived that the augumentation in the water-supplying power of the soil which accompanies torrential rains after a period of comparative drought should normally be followed by a considerable increase in turgor pressure throughout the plant body; in some cases this is even sufficient to rupture the cell walls.

It has also been observed that a serious shedding of young fruits—e.g., cotton – is liable to occur under these conditions. It is still doubtful to what extent this is due, either directly or indirectly, to the sudden augmentation in the water-supplying power of the soil, and to what extent to such extraneous factors, as limitation of air supply in the soil or destruction of pollen, and other phenomena which may accompany torrential rains. It will be patent that the rate of increase in the water-supplying power of the soil for a given rate of rainfall should be greater the less colloidal the nature of the soil. The effects accruing from sudden changes in the water-supplying power of the soil are unquestionably of considerable economic and ecological significance, and could be profitably investigated by means of the soil-point method.

(b) It will be evident that the forces of imbibition of the soil-points, which have been employed in this investigation, operate only against the surface forces with which the soil retains itsmoisture. On the other hand, when an osmometer is used for the determination of the water-supplying power of the soil, work is done not only against the surface forces of the soil but also against the osmotic pressure of the soil solution. Now the water-attracting forces of the plant root, which appear to be numerically equal to that portion of the osmotic concentration

of the cell sap which is in excess of the turgor pressure[14], must also contend with the osmotic pressure of the soil solution. It should follow, therefore, that if permanent wilting were normally due to the development of excessive osmotic pressures in the soil solution, as Bouyoucos and McCool[4] suggest, and if these pressures were to fluctuate considerably from soil solution to soil solution, that the values obtained for the water-supplying power by soil-points, which take no direct account of the osmotic pressure of the soil solution, should show similar fluctuations. It has been found, however, that though significant variations do occur, they are negligible in comparison with the total range of water-supplying power liable to be encountered by the roots of plants. Reference to Table III shows, moreover, that these variations are in general not fortuitous, for a tendency exists for the index of water-supplying power to decline in company with the soil moisture residue at permanent wilting. It is possibly more than a co-incidence that Livingston and Koketsu observed a similar tendency when wheat plants *Triticum sativum* were employed as biological indicators. It is conceivable that this is due to a more perfect root distribution in soils containing a relatively small proportion of colloids.

(c) The ratios between the moisture residues at the time of permanent wilting and the percentages of moisture in the soils at the point of maximum plasticity are shown in Table V. It will be observed that though the degree of correlation is high, yet there is still a considerable range; nearly 40 per cent between the ratios of B and G. It may also be noted that these ratios tend to increase as the value of the soil moisture residues at permanent wilting decrease. This too may be due to a more perfect root distribution in the lighter classes of soil. The nature of the correlation between the soil moisture residues at permanent wilting and the moisture contents at the point of maximum plasticity, appears to indicate, assuming the latter to be proportional to the soil's interior surface, that some factor or factors in addition to the colloidal nature of the soil are responsible for the soil moisture residues at permanent wilting. One presumes that differences in the rate of water transmission through the soil resulting from differences in texture and compression, and the ease of root penetration, must have played a part in determining the soil moisture contents at permanent wilting.

TABLE III.

Water-supplying Power and Soil moisture. Residue at Permanent Wilting.

No. of Culture.			I			II.			III.			IV.			V			Mean.
No. of Observation.			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Water-supplying Power of Soil at Permanent wilting (hundredths of a gram).	Soil.	A.	2·9	3·1	3·0	3·9	3·3	2·9	3·6	3·4	2·8	3·0	2·5	2·9	3·1	2·7	2·9	3·07±0·063
		B.	3·7	3·0	3·3	3·7	3·0	3·3	2·3	2·8	2·9	2·9	3·1	3·3	2·8	2·6	3·5	3·05±0·071
		C.	2·5	2·1	2·9	3·1	2·6	3·6	2·4	4·1	2·7	2·2	2·7	2·8	3·0	3·6	3·6	2·95±0·096
		D.	3·3	3·0	3·1	3·5	3·7	3·4	2·8	3·1	3·8	3·4	3·2	2·7	3·2	3·2	3·0	3·33±0·056
		E.	2·3	2·1	2·1	2·7	2·4	2·6	2·7	2·4	2·5	2·2	2·2	2·6	2·5	2·1	2·9	2·42±0·044
		F.	3·1	2·6	2·4	2·3	2·3	3·4	2·3	2·8	2·9	3·0	2·6	2·8	2·9	2·3	2·5	2·68±0·059
		G.	2·5	2·6	2·6	2·4	2·2	2·6	2·4	2·9	2·5	2·1	2·4	2·0	2·2	2·9	1·7	2·40±0·053
Soil Moisture Residue at Permanent wilting.	Soil.	A.		35·3			32·4			32·9			33·1			32·5		33·3 ± 0·33
		B.		31·7			31·5			31·1			30·9			31·3		31·3 ± 0·14
		C.		24·5			30·2			24·5			26·9			29·2		27·1 ± 1·07
		D.		23·5			24·6			24·7			25·6			26·4		25·0 ± 0·33
		E.		17·8			15·3			19·2			16·5			17·7		17·3 ± 0·45
		F.		14·4			17·3			15·7			20·4			14·3		16·4 ± 0·76
		G.		11·3			12·9			11·6			15·5			16·8		13·6 ± 0·73

Table IV.

Water-supplying Power and Soil moisture Content at Point of Maximum Plasticity..

No. of Sample.			I.			II.			III.			IV.			V.			Mean.
No. of Observation.			1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Water supplying Power of Soil at point of maximum plasticity (hundredths of a gram).	Soil.	A.	14·4	14·4	15·0	27·0	24·6	1·0	10·8	13·2	13·2	29·4	19 8	19·8	1·44	22·2	21·6	18·7 ± 0·99
		B.	12·0	11·4	10·8	19·2	13·8	24·0	11·4	13.2	14·4	10·2	18·6	12·0	10 8	1·0	11·4	13·7 ± 0 68
		C.	12·0	11·4	13·8	10·8	14·4	13·8	13·8	12·6	†	12·0	15·6	15·0	12·0	13·8	14·0	13·2 ± 0·26
		D.	24 6	11 4	13·2	18·6	9·0	10·8	10·8	12·6	10·8	13·2	15·0	15·0	16·8	12·0	13·0	13·7 ± 68·0
		E.	10 8	15·0	10·8	11·4	12·6	8·4	10 8	18·0	10·8	14·4	9·0	†	10·2	15·0	7·2	11·7 ± 45·0
		F.	12·6	14·4	18·0	12·6	14 8	14·4	19·2	12·0	11·4	15·0	17·4	15·0	13·2	12·0	12·6	14·3 ± 0·40
		G.	34·2 *	15·0	18·6	18·0	18·0	15 0	20·4	12·0	18·0	39·0 *	19·2	16·8	27·6	19·8	12·0	1·77 ± 0·74
Soil Moisture content at point of maximum plasticity.	Soil.	A.	50·0			50·9			47·3			49·9			47·9			48·2 ± 0·99
		B.	47·7			44·3			45·7			43·9			45·9			45·5 ± 0 14
		C.	43·2			43·5			45·1			†			†			43·9
		D.	38·3			39·8			40·3			40·3			40·1			39·8 ± 0·10
		E.	35·3			34·8			35·9			36·5			34·4			35·4 ± 0··5
		F.	31·4			30·8			30·1			30 8			30·9			30·8 ± 0·14
		G.	23·5			25·9			23·5			23·6			23·3			24·0 ± 0·33.

* Not included in mean. † Not determined

TABLE V.

Soil.	A.	B.	C.	D.	E.	F.	G.
(a) Soil moisture Residue at permanent wilting.	33·2	31·3	27·1	25·0	17·3	16·4	13·6
(b) Soil moisture content at point of maximum plasticity.	48·2	45·5	43·9	39·8	35·4	30·8	24·0
Ratio $\frac{b}{a}$	1·45	1·45	1·62	1·59	2·05	1·88	1·76

SUMMARY.

(1) An outline is given of the more important methods which have been employed in the determination of the physiological moisture conditions of the soil.

(2) A simple method of measuring directly the water-supplying powers of soils by means of lead writing pencils has been described

(3) Since soils at the time corresponding to the permanent wilting of plants rooted in them are all similar, as far as their capacity to supply water to the plants is concerned, the values obtained by this method should show a close agreement. This was found to be the case in seven soils of varying texture.

(4) A high degree of correlation was found to exist between the colloid content of the soils, as measured by the water of imbibition at the point of maximum plasticity, and the soil moisture residues at permanent wilting.

In conclusion the writer has pleasure in acknowledging his indebtedness to Dr B. E. Livingston, at whose suggestion the work was undertaken.

LITERATURE.

(1) Alway, F. J. *Res. Bull.* No. 3 Agricultural Experiment Station, Nebraska, 1913.

(2) Alway, F. J. and McDole, G. R. *Jour. Agric. Res.* 9 2 27-71, 1917.

(3) Alway, F. J. and McDole, G. R *Jour. Agric. Res.* 14 11, pp 453-80, 1915.

(4) Bouyoucos, G. J. and McCool, M. M. *Tech. Bull.* No. 31, Michigan Agricu'tural College Experiment Station, 1916.

(5) Briggs, L. J. and Shantz, H. L. *Bull.* 230. Bur. of Plant Ind. U. S. Department of Agriculture. 1912.

(6) Caldwell, J. S. *Physiological Researches* 1, 1, 1-56, 1913.
(7) Clements, F. E. Research Methods in Ecology, Lincoln, Nebraska, 1905.
(8) Crump, W. B. *New Phytologist*, 12, 4 and 5, 125-47, 1913.
(9) Fowler, L. W. and Lipman, C. B. University of California. *Pub. in Agric. Sci.* 3, 2, 25-30, 1917.
(10) Free, E. E. *Plant World*, 14, 29, 39, 110-19, 1911.
(11) Gain, E. *Rev. Gen. de Bot.*. 7, 15-20 71-84 123-38, 1795.
(12) Hedgecock, G. G. Bot. Sur. of Nebraska, 6, 57-79, 1902.
(13) Livingston, B. E. and Koketsu, R. *Soil Science*, 9, 6, 469-85, 1920.
(14) Mason, T G. *West Indian Bulletin*, XVIII 4, 157-84, 1921.
(15) Pulling, H. E. and Livingston, B. E. Carnegie Inst. of Washington *Pub.* 204, 51-84, 1915.
(16) Rohland, P. quoted in T. e Third Report on Colloid Chem. and its General and Industrial Application. Department of Science and Ind Res. 117, 133, 1920.
(17) Sachs, J. Lan wirthschaftlichen Versuchs-Sthtionen. 1, 235, 1859
(18) Shull, C. A. *Bot. Gaz.* 62, 1, 1-31, 1916.

THE PREPARATION OF HIGH GRADE SUGAR-CANE SYRUP.

BY A. E COLLENS AND F. H. S. WARNEFORD,
Government Laboratory for the Leeward Islands.

Considerable interest attaches to the manufacture of cane syrup, in view of the facts that it is more easily manufactured than sugar, and it commands a price which compares favourably with that of muscovado sugar.

Certain standards are set, however, which must be reached by a marketable article. Tempany (*W. I. B.*, Vol. XIII, p. 324) states: 'The requirements of a good syrup may be stated as follows:—

'I. It should possess a density of not less than 40° Beaumé
'II. It should test not more than 48° and not less than 32° by the polariscope.
'III. It should be free from fermentation and pronounced flavour of acidity.
'IV. It should not crystallize even on prolonged standing.
'V. It should be free from all traces of mineral acid.
'VI. It should be clean, free from suspended impurities, bright, and of a golden colour.'

The manufacture of cane syrup is dealt with at some length in the article referred to above. A somewhat condensed version of this article has appeared in the *Agricultural News* of January 24, 1920.

Since the publication of the articles mentioned, Dr. Zerban, of the Louisiana Sugar Research Institute, has published an account of his experimental work on the defecation of cane juice by certain colloidal agents.* The excellent results which he has obtained by his new process suggested the possibility of its application to the production of high grade cane syrups in the West Indies.

At the same time, in view of the varying nature of the product manufactured in the Leeward Islands, it was considered desirable to ascertain if it would be possible to keep a rather close check on the polarization of the finished product without introducing too complex a system of chemical control to be carried out by any intelligent overseer.

The polarization of a cane syrup depends to some extent on the purity of the juice from which it was made, and on the density of the finished syrup—but to a great extent also on the amount of inversion taking place during its manufacture.

The factors controlling the degree of inversion which takes place during concentration are :—

1. Rate of inversion.
2. Total period of concentration.

The rate of inversion itself depends on several factors—the most important being :—

1 The concentration of the sucrose.
2 The temperature of the reaction mixture.
3. The concentration of the inversion catalyst, i.e. the concentration of naturally occurring acid present.

Factor 2 varies throughout the reaction as the boiling point of the liquid rises with increasing concentration.

The concentration of the catalyst is also a varying factor. Evaporation of the syrup and the consequent diminution in volume tend to increase the concentration of the acid. On the other hand part of the acid formed during the spontaneous souring of cane juice is volatile,* and is lost on evaporation—thus tending to lower the concentration.

It should be noted here, moreover, that it is not the actual amount of ionisable acid present which determines the rate of inversion, but the concentration of hydrogen-ion. This will vary with the acid formed. Hydrogen-ion concentration cannot be measured by titration with alkali, and in the case of a deeply coloured liquid such as cane juice, the simple colorimetric methods for hydrogen-ion estimation become unreliable, and recourse must be made to the hydrogen electrode—too complicated a method to function in a simple manufacturing process.

It has been found, however, that determination of the initial acidity of a juice by titration with N/2 Na OH and phenol phthalein—together with a control of the time factor—allows of the production of a syrup polarising within the limits quoted above.

---

*Filter-cel : an infusorial earth, and Norit : a vegetable charcoal.
*Watts & Tempany, *W. I. B.*, Vol. VI, p. 387.

Control of the Inversion.

Tempany (*loc. cit.*) recommends the addition of a definite volume of sour juice approximately twenty-four hours old to each batch of fresh juice. The quantity of sour juice required is stated to vary in different districts—from nothing in the northern cane-growing district of St Kitts up to 60–80 gallons per clarifier in the limestone area of Antigua.

The acidity developed under normal conditions in twenty-four hours is stated to vary within relatively narrow limits. On the other hand, the rate of souring in the case of differe t varieties appeared to be subject to variations of some magnitude.

The following figures obtained by us for the acidity o various mixed juices twenty-four h urs old indicate that at times the variation from the mean value may be great enough to affect seriou sly the degree of inversion taking place.

100 c.c.	equals	12·0 c.c. $\frac{N}{2}$	acid.
100 c.c.	„	18·5 c.c. „	„
100 c.c.	„	20·0 c.c. „	„
100 c.c.	„	22·0 c c. „	„
100 c.c.	„	28·0 c.c. „	„
100 c c.	„	29 0 c.c. „	„

Experiments were made to determine whether, when the time factor was kept constant, any close relationship exi-ted between the polarisation of the finished syrup and the initi l acidity of the juice as determined by titration.

Seven batches of syrup were made. The initial acidity of the juices varied from ·043 to ·108 c.c. N/2 acid per c.c. of juice, and was adjusted by mixing fresh and sour juices of known acidity in the desired proportions.

In each case the density of the resulting syrup was 40° B_e and the total time of heating—including defecation,* which was carried out with filter-cel, was approximately two hours.

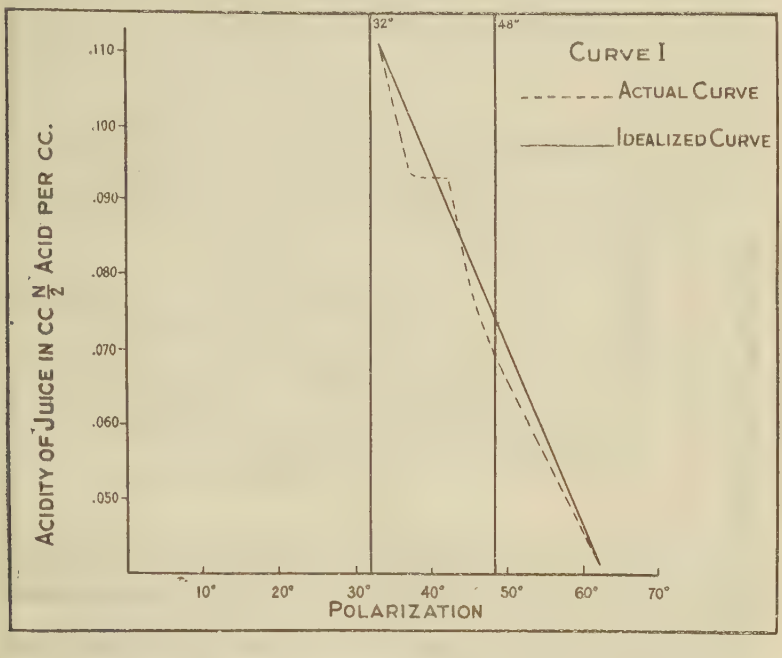
The following results were obtained :—

Experiment.	I.	II.	III.	IV.	V.	VI.	V '.
Acidity of juice in c.c. N/2 acid per c.c. juice ...	·043	·054	·066	·081	·093	·093	·108
Polarization of syrup ...	61°	55°	50°	44°	37°	42°	33°

*Defecation with filter-cel exerts but litttle change on the acidity of the juice.

200 c.c. juice of total acidity equivalent to 15·3 c c. N/2 acid was heated to boiling with 2 gms. filted cel. The acidity of the filtrate was equivalent to 15 c.c. N 2 acid.

The polarisation values of the syrups are plotted against the initial acidity of the juices (expressed as c.c. N/2 acid per c.c. of juice) in curve I.



As will be seen, the curve approximates to a straight line within the limits of acidity investigated—indicating the close relation existing between the final polarization and the initial acidity of the juice as determined by simple titration.

The time factor was next investigated. A juice whose initial acidity was 1 c.c.=·071 c.c. N/2 acid was converted into syrup of 40° Beaumé in three and a quarter hours The heating during defecation required a quarter of an hour, so that the total time of uninterrupted heating was three hours.

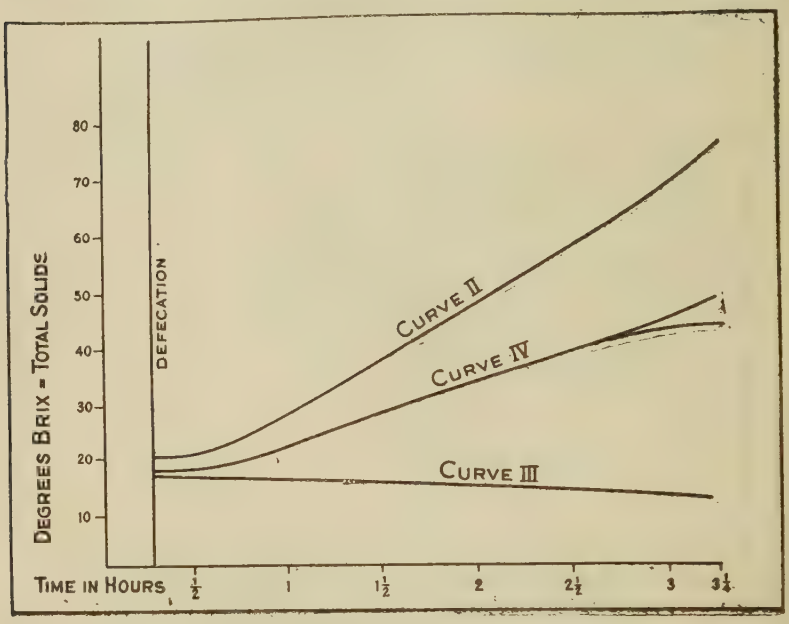
The density (degrees Beaumé) and the polarization of the freshly defecated juice were taken ; and at various intervals further samples were withdrawn for the determination of these values. In each case, besides polarizing the syrup a portion of the sample was diluted to 11° Beaumé (the density of the defecate djuice) and the diluted sample polarized.

The density in degrees Beaumé has been converted into total solids (Brix), and these values and the corresponding polarizations of the diluted and undiluted syrups have been plotted against time in curves II, III, and IV. Curve III is a measure of the inversion taking place during any given period.

The lag in all the curves observed during the first quarter hour period after defecation is due to the fact that the temperature did not reach 100° until the end of this time.

Consideration of the curves indicates that for a syrup concentrated in two hours, an initial acidity of about ·085 c.c. N/2

acid per c.c. is desirable ; while if the time of concentration is three hours, the initial acidity should be about ·075 c.c. N/2 acid per c.c.



In practice it may sometimes happen that the quantity of sour juice on hand is so large that were it all mixed with the available fresh juice, too acid a mixture and consequently too much inversion would result.

It is therefore advisable to manufacture a syrup polarizing somewhat near 48°—the upper limit—so that should at any time the manufacture of a syrup of low polarization be inevitable, an admixture of this low polarizing syrup would not depress the polarization of the mixture below 32°.

The Filter-cel Process.

Defecation. A mixture of fresh and sour juice in the requisite proportions to contain the acid needed to produce the desired degree of inversion is heated to boiling in the course of fifteen to twenty minutes with from ·5 per cent. to 1 per cent. by weight of its volume of filter-cel. The hot liquid is either filtered through felt or flannel bags, or allowed to settle, the sediment only being filtered. In either case the defecated juice is obtained as a clear amber-coloured liquid. ·5 per cent. weight by volume seems to be the lowest limit to the amount of filter-cel which brings about a satisfactory defecation. When the defecated juice is to be filtered, a higher percentage of filter-cel about 1 per cent. gives the most satisfactory results. On the other hand, when sedimentation for a couple of hours is resorted to the volume occupied by the sediment is smaller when the lower percentage of filter-cel is used.

In two sedimentation experiments the following results were obtained:—

A. 1 per cent. filter-cell : Sediment = 18 per cent. total vol. of juice
B. ·5 per cent. „ „ „ = 13 „ „ „ „ „

Where sedimentation is used, the last portions of the juice which contain the sediment filter readily through flannel, giving a satisfactory filtrate.

Concentration The clear juice is heated over a naked flame until the temperature of the boiling liquid rises to 107-108°C. A sample is then removed for determination of density. If this value is 35° Beaumé in the hot juice, the syrup will have a density of 40° Beaumé in the cold, and concentration is complete.

During the last stage of concentration a gummy froth rises to the surface : this is removed by skimming, leaving a bright golden brown to reddish brown syrup.

In our experiments concentration was carried out in enamelled vessels. In one experiment, however, a number of iron nails—some being rusty—were placed in the boiling juice for the whole period of concentration. No appreciable effect resulted as far as appearance of the syrup is concerned.

Yield.

Yields expressed as c.c. of syrup per 100 c.c. of juice convey little information, as there is a considerable variation in the total solids content and purity of the original juice.

The yield expressed as the percentage of total solids in the juice recovered in the syrup—when accompanied by the purity of the juice—affords a better indication of the loss taking place during the process.

The following results* were obtained in two experiments which were carried out to ascertain the yield :—

Expt.	Weight of total solids in juice.	Purity.	Loss during defecation.	Weight of total solids in syrup of 40° Beaumé	Total loss.	Yield.
I.	318 gms	83%	17 gms.—4·9%	272 gms	76 gms. = 23%	78 %
II.	428 „	86%	21 „ = 4·9%	372 „	56 „ = 13%	87 %

It will be noticed that the loss during defecation proper is small. The further loss of 8 per cent. to 17 per cent. is due to the separation of gummy matter during concentrating : this either sticks to the wall of the concentrating vessel or is removed by skimming. In neither case is it measured with the finished syrup.

Cost of Process.

The highest percentage of filter-cel used is 1 per cent. weight by volume, that is to say ·1 gm. per 10 c.c. which is about equivalent to 1 lb. per 10 gallons.

*Applicable only under laboratory conditions.

In the experiment in which the yield reckoned on the total solids was 87 per cent. 345 c.c. of syrup were obtained from 2,000 c.c. of juice. That is, 345 gallons of syrup would be obtained from 2,000 gallons of juice. For this quantity of juice, 200lbs. filter-cel would be used. This is equivalent to ·58 lb. per gallon of syrup.

Filter cel bought in car load lots directly from the factory costs 1¾c. per lb. If we allow 2¼c. for exchange, freight and duty, it would costs 4c. landed in the British West Indies—whence the cost per gallon of syrup would be 2·32c.

To calculate the total cost of production, the individual manufacturer must add the cost of fuel and labour, barrels, overhead charges, etc.

It is probable that the filter-cel used could be revivified by ignition at a temperature high enough to destroy the adsorbed organic matter.

The Norit Process.

We have made a few experiments using norit in conjunction with filter cel. The syrup produced was of a fine honey colour, but the difficulty of filtering from the norit prevented a full investigation of the process.

Since the conclusion of the work recorded above, reference has been made in *The Journal of Industrial and Engineering Chemistry*, June 1921, 'The manufacture of Citric Acid from Lemons,' to the use of carbonized filter-cel as a filtering agent. This product is obtained by heating to a bright red heat in closed retorts, the press cake obtained on filtering raw lemon juice treated with filter-cel. It is claimed that the carbonized filter-cel has a decolourising value, and is a much better aid to filtering that fresh unused filter cel. A similar product could probably be made by ignition in closed vessels of the filter-cel used in the defecation of the cane juice.

LIMING AS A MEANS OF SOIL AMENDMENT.*

BY F. HARDY,

Chemist, Imperial Department of Agriculture
for the West Indies.

I. Introductory.

Liming for increasing crop production has been practised since the earliest times Records show that it was known to the cultivators of the grape vine in the time of Hesiod (B.C. 1100). In the absence of scientific knowledge of the effects of liming, the crudest rule of thumb methods were used. Between the years 1850 and 1900, the development of the fertilizer industry, and the wide spread belief which grew up in those days that mineral manures could rectify most of the deficiencies exhibited by infertile soils, led to the almost total abandonment of liming as a major operation in soil cultivation. Agricultural writings up to the beginning of the present century contain but scant and indefinite reference to the practice, especially in connexion with its value as a remedy for soil sourness. The rapid strides which have recently been made in soil science have resulted in increased attention being given to the various aspects of liming.

The first accurate knowledge gained as to the effect of adding lime to the soils was in relation to the improvement it brings about in the texture of soils of high clay content, and the power which it is sometimes stated to possess in liberating plant nutrients from pre-existing supplies in the soil, or from added organic or inorganic manures Recently the subject of soil sourness has been investigated in some detail, and the accumulation of knowledge has led to a more accurate understanding of relationships between the several factors presented by sour soils and the growth of plants rooted in them.

In a previous article in this Journal[21] † the writer has attempted to review the main facts connected with the significance of sourness in soils as recorded in modern literature. The following account of the theory of liming is intended to be a sequel to that article, and is based on the conception of soil sourness therein presented.

The various substances that go by the name of lime in agriculture include the following compounds of calcium: (1) calcium oxide (quicklime, burnt lime, CaO); (2) calcium hydroxide (slaked lime, hydrated lime, calcium hydrate, $Ca(OH_2)$; and (3) calcium carbonate (limestone, coral rock, chalk, etc., $CaCO_3$). When added to any particular type of soil, lime exerts various distinctive effects, the nature of which depends on the composition of the substance (whether oxide, hydroxide or carbonate),

* Received for publication March 31, 1921.

† Reference is made by number to the bibliography tabulated as an appendix to this article.

the degree of subdivision of the material, and the amount that is added per unit area.

There appears to be no advantage in using quicklime at a soil amendment in preference to the other forms of lime, except in so far as it lessens freightage expenses because of the fact that its weight is only three-fifths of the weight of a chemically equivalent amount of calcium carbonate, and in so far as is may exercise certain distinctive effects on the micro-organic population of the soil. It is well known that quicklime rapidly becomes slaked when exposed to the action of moisture, and that both quicklime and slaked lime give rise to the carbonate when placed in contact with carbonic acid or moist carbon dioxide.

McIntire [43] in a lengthy critical and experimental study of the carbonation of quicklime has cleared up much of the vague information heretofore recorded in scientific literature. He has established the fact that the carbonation of quicklime is always preceded by the hydration of the compound according to the equations $CaO + H_2O = Ca(OH)_2$ and $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$. The two reactions may be so repaid, however, as to be considered as simultaneous. In field cylinder experiments McIntire found that 2 tons of quicklime or of slaked lime per acre of soil were converted into carbonate within five days after being mixed with the top 6 inches of soil. When slaked lime was left as a surface layer unmixed with the top soil, carbonation was even more rapid, especially during humid atmospheric conditions.

It thus appears that if a dressing of quicklime or of slaked lime is left on the surface of a soil for several days prior to inworking, the treatment is in effect an application of finely divided calcium carbonate.

The state of subdivision in which lime is applied to soils is of considerable importance, for the greater the surface area exposed by the lime to the soil and the soil solution, the greater will be the rate of reaction between the lime and the soil constituents. That this has its effect on the productivity of soils has frequently been demonstrated by field trials. Thus Kopeloff [35], after reviewing the work of other investigators in this field up to 1917, states that his own researches prove that an increase in the fineness of division of pulverized limestone is responsible for a proportional increase in the yield of red clover on soils representative of many fertile areas in the United States. He found that there was little choice between quicklime and 200-mesh limestone. He further noted that the use of ground limestone in decreasing degrees of fineness was accompanied by corresponding increases in the activity of the bacteria that cause ammonification, nitrification and nitrogen-fixation. This fact was correlated with the chemical factors involved, such as the rate of neutralization of acidity, etc.

Frear [14] also reports similar results obtained by him in experiments at the Pennsylvania Experiment Station, and by other workers at various centres both in Europe and America.*

*See also p. 170.

The various Effects which Liming Exerts on Soils and the Interrelationships that Exist between Them.

In considering the effects of lime on the soil, and consequently on the growth of plants, it would be advisable first to refer to the chemical changes that go on when calcium carbonate is brought into contact with the soil water and the soil atmosphere. In the writer's previous article[21] (p. 57) the calcium carbonate – carbon-dioxide system was described, and its ionic equilibrium relationships were discussed in some detail. It was therein shown that calcium carbonate, introduced into soils deficient in this compound, can bring about a depression of hydrogen-ions concentration in the soil solution. The occurrence of acid substances in certain soils is responsible for the presence of hydrogen-ion in the soil solution to a degree of concentration measurably in excess of that exhibited by pure water. Calcium carbonate gives rise to calcium bicarbonate when exposed to the action of carbonic acid. This bicarbonate is partly hydrolysed in solution so as to yield hydroxyl-ions. These are the agents which primarily operate in removing hydrogen-ions in acid soil solutions. Thus the presence of calcium carbonate in a soil may result in a complete suppression of hydrogen-ions, in excess of that concentration of hydrogen-ion exhibited by pure water, and even to so great an increase in the concentration of hydroxyl-ions that the soil solution comes to possess a markedly alkaline reaction. Before this can occur, however, the buffer action of certain compounds present in it must be completely overcome. [21] (p. 57)

Calcium bicarbonate in the soil solution furthermore gives rise to a greatly increased concentration of calcium-ion, for the bicarbonate is a very soluble compound and is capable of a high degree of dissociation. [21] (p. 66.)

In attempting to explain the several and complex effects which the addition of lime to soils may bring about in those soil-conditions that affect plant growth, it would appear reasonable to distinguish between the effects due to the calcium-ions and those due to hydroxyl- and to the bicarbonate-ions that are yielded to the soil solution as a result of the treatment. In reality, however, such a distinction between the specific ionic effects can scarcely be drawn, for in certain cases more than one of the ions is operative in producing a given result. The extent to which any one of the three ions—calcium-ion, hydroxyl-ion and bicarbonate-ion—participates, can nevertheless be estimated in some degree, as may be gathered from a study of the facts which will hereafter be presented.

The various effects which liming brings about in soils may be tabulated and summarized as follows:—

1. Liming frequently alters the texture of soils because of its physico-chemical action on the finer particles, causing in many cases an agglomeration of these particles with an accompanying improvement in tilth. Improved tilth leads to increased aeration, and this profoundly modifies many of the processes that go on in soils.

2. The hydrogen-ion concentration of the soil solution is depressed to a degree depending chiefly on the amount of lime added.

   The ultimate hydrogen-ion concentration of the soil solution controls to a great extent many of the processes that go on in the soil, such as the activities of the micro-organic fauna and flora, and the absorption of water and of certain ions that serve to nourish the plant.

3. Soils deficient in calcium have their calcium content increased by liming, so that plants growing in these soils may not suffer from lack of this element as an essential factor in their normal internal metabolism.

4. Calcium-ions antagonize certain other ions that are toxic to plants or to bacteria, and thus minimize the absorption of these ions in amounts liable to cause injury.

5. Liming brings about the precipitation of certain toxic organic and inorganic substances in the soil solution of certain soils by reacting chemically with them. This effect must be distinguished carefully from the antagonistic effect due to the calcium-ion as outlined in the last section.

   When present in great excess, liming may bring about an almost complete removal from the soil solution of certain ions essential to growth, and in this way may exercise a deleterious effect on fertility.

6. Calcium-ions are said to displace certain other ions, such as those of potassium from mineral silicates, and also to displace assimilable phosphate from certain other inorganic soil compounds, and in this way to increase the availability of these ions to plants.

The above-mentioned effects will in turn be considered in detail, and explained as far as possible in the light of modern knowledge. The results of recent experiments, performed both in the laboratory and in the field, that have bearing on the facts mentioned will be reviewed, and an attempt made to correlate the data, so that a comprehensive idea of the intricate and complex effects of adding lime to the soil may be obtained.

It is not to be supposed that the addition of lime to any particular soil, produces in any definite order effects such as those named in the above list. One cannot say, for example, that excess of lime applied to a sour clay soil will in every case first neutralize the acidity and then flocculate colloidal substances present, or that it will first bring about flocculation and then neutralization. In most cases the various effects of liming are produced simultaneously; but there is evidence to show, however, that in certain instances the effect of liming is to bring about its distinctive results in some definite sequence.

The whole question of the changes that occur when soils are limed is one of the adjustment of equilibrium in a complex system containing many interrelated factors. Any change in external conditions will effect this equilibrium, and readjustments will follow. The complexity of the reactions that proceed in soils of different types when lime is added to them explains in some measure the discrepancies that have arisen in liming

experiments. Sufficient care has not been taken in all cases, carefully to distinguish between the various phases of the problem, in particular the relation of the plant to the soil.

Investigations into the specific effects of liming present the same difficulties, and are open to the same objections as various other kinds of biological experimentation, for it is almost impossible to control all the variable factors presented by the soil-plant system during a study of any single factor which is directly under observation.

It is only by means of a thorough understanding of the numerous effects that lime exerts in the soil, however, that the particular problem can be solved, of why, when, and how a given soil should be limed with a view to increasing its productivity.

1. THE EFFECT OF LIMING ON SOIL TEXTURE.

The improvement in tilth which liming brings about in clayey soils is given great prominence in all writings on soil management. Much research work has been carried out to find an explanation of the mechanism of this effect of liming, and to attempt to discover the quantitative laws that underly it.

The progress of colloid chemistry has furnished many data which have thrown light on the phenomenon of coagulation or flocculation of the finer particles of the soil as brought about by certain substances. It has long been known that salts and acids (electrolytes) added to colloid dispersoids cause coagulation. The reason for this has been referred to the changes in electrical state of the dispersed particles caused by their adsorbing certain ions yielded by the ionic dissociation of the electrolyte. It has been supposed that clay particles, for instance, are negatively charged when suspended in water, and for this reason each particle repels every other similar particle, so that aggregation is prevented. When the particles adsorb positively-charged ions, however, their negative charges are neutralized; the isoelectric point is thus reached, and the particles are now no longer kept apart by electrostatic forces. Surface attraction or cohesion is able to operate, and aggregation ensues.

In order to gain some knowledge of the properties of colloidal substances in soils, numerous experimenters have studied suspensions of kaolin and of other naturally occurring clays. As early as 1886, or only a few years after the publication of Graham's classical researches on colloidal substances, Schulze recorded results on the calcium and magnesium salt requirements for flocculation of clay suspensions. Hilgard in 1877 also studied the effect of lime on the texture of clays. Later it was claimed by several investigators (for example, Schulze in 1882 and Spring in 1900*) that the flocculating power of a salt depends on the valency of the metal present in it. The ratio 350:20: 1 was developed by Schulze as representing the relative coagulating powers of trivalent, divalent, and monovalent metallic ions, respectively.

Hall and Morrison[20] studied the efficiency of various acids and salts on the flocculation of kaolin suspensions. With the

commoner acids they found that order of efficiency to be $HCl > HNO_3 > H_2SO_4$, and for certain metallic ions $Al > Ca > K > Na$. Wolkoff[57] investigated the flocculation of several, soils, and showed that the flocculation efficiency of any given soil on salt suspensions varies with the chemical constitution of the soil, and that Schulze's valency law did not hold true for the soils studied. Humic substances were found to hinder the coagulating power of the flocculating agent.

The valency law is nowadays regarded as unsubstantiated, for certain recent researches have revealed cases in which the relationships between the precipitancy power of ions is not even in approximate agreement with that between their valencies.

So far the flocculating action of electrolytes has been referred chiefly to their electro-positive ions, for instance, the metallic ions deliberated when salts dissociate. The results now to be present indicate that the electro-negative ion is also effective in regulating the degree of agglomeration which colloidal substances in soils may suffer when brought into contact with electrolytes. The phenomenon has long been known, but little experimental work has been recorded on this phase of the subject. Comber[9] has recently described interesting experiments on the flocculation of soils, in which he points out that, in any attempt to correlate the flocculation of soil particles with the established facts of modern colloid chemistry, attention must be paid to the complication of the soil system. There are two obvious causes of complication, each of which will have an important bearing upon the action of electrolytes in the soil ; first, the soil particles are protected by organic and inorganic colloidal substances ; and second the soil is a system of particles of all degrees of size.

Comber's experiments were carried out with silt, clay, and soil. The flocculation of these in solutions of neutral and of alkaline reaction was studied. It was demonstrated first of all that alkalinity decreases the flocculating effect of calcium-ion on *silt*. This appears to be in full accord with the electrical theory of flocculation as outlined above, for, if we assume the silt particles to possess negative charges, and their flocculation to be due to the neutralization of these charges as a result of the adsorption of positively charged calcium ions, it follows that, when the silt particles also adsorb negatively charged hydroxyl-ions, in addition to the positively charged calcium-ions, the flocculating power of the latter becomes reduced. Hence calcium hydroxide is not so good a flocculant for silt as calcium bicarbonate or calcium nitrate.

Comber found, however, that the effect of alkalinity on *clay* presented quite another case. Here the presence of hydroxyl-ions is observed to increase the flocculating effect of calcium-ion. Thus calcium hydroxide is a better flocculant for clay than neutral calcium salts.

Comber explains this difference between silt and clay by assuming that the colloidal state of the two is widely different. Colloid chemists have long distinguished between the colloidal state exhibited by such substances as silicic acid and the gums, which are not easily coagulated by electrolytes, and which are able to absorb water in large quanties, and non-gelatinizing

substances which are easily coagulated, and which exhibit no marked tendency to absorb water and swell. The two classes o substances have been referred to as emulsoid and suspensoid substances, respectively. According to this nomenclature, clay is to be regarded as an emulsoid, and silt as a supensoid substance.

It has repeatedly been demonstrated that, in the case of the emulsoid colloids, the importance of the electrical state is not so great as in the case of the suspensoid colloids. The electric charge associated with the former is frequently accidental and less characteristic. In some instances its sign may be reversed simply by altering the reaction of the medium in which the emulsoid colloid is held.

It seems highly probable that the clay particles of a soil are protected or covered by some such emulsoid substance as silicic acid or a complex of organic substances belonging to the so-called humus component of the soil. The physico-chemical properties of the particles will be coincident with those of the protecting emulsoid material. This will account for the differences that have been noted in the colloidal properties exhibited by kaolin and by soil clay, as has already been indicated (See Wolkoff[57] p. 587.)

The action of calcium hydroxide and of calcium carbonate as flocculants of clay has generally been regarded as anomalous, for it has usually been taught that alkalies are deflocculants of clay, whereas it is known in practice that these two calcium compounds usually behave very effectively as flocculants. If the emulsoid character of true clay is admitted, then calcium hydroxide is seen to be an ideal flocculant, for the calcium-ions and the hydroxyl ions are not working in opposition but in co-operation. The hydroxyl ions remove the emulsoid from its isoelectric point, and thus render it less stable; the calcium-ions then coagulate the unstable emulsoid.

Comber suggests that clay – itself a protected colloid—functions in the soil as a protective colloid. Siliceous and organic emulsoids appear to protect the clay particles, and the clay appears to protect the silt. Hence fine silt soils are not flocculated by calcium hydroxide on account of the insufficiency of the relatively small amount of emulsoid clay to protect the large surface exposed by the fine silt. True clay soils, on the other hand, are readily flocculated by calcium hydroxide because the emulsoid characters of the clay predominate in the soil. In this way many of the perplexing irregularities in the observed effects of liming on the texture of different types of soils may be explained.

Non-flocculated clay soils are notoriously non-permeable, and for this reason oxidation in them is usually lacking. Aerobic bacterial activity is low, and plant residues decay in such a way that acidic and toxic organic compounds tend to accumulate. The soils thus become sour and unproductive. The clay land farmer experiences exceptional trouble in bringing clay soils into cultivation. His chief aid is liming, for this brings about flocculation of the true clay particles, as has been described above. Good aeration follows on good tilth. Beneficial micro-organisms become profilic; toxic and acidic organic compounds

are oxidized and rendered innocuous, and a high state of fertilite is induced.

That liming actually does bring about in the majority of cases the sequence of changes indicated, has repeatedly been proved in farming practice. The various stages have also been demonstrated in numerous field experiments which have been laid down to compare the effects of liming upon crop yield, or upon the rate at which various soil processes go on. Whilst it is well nigh impossible in agronomic experimentation to distinguish between, and to measure, the many ways in which liming improves soil conditions, there is no doubt that the improvement in tilth which liming induces is one of the chief benefits of the treatment. Thus Neller [47] in examining the effect of liming on the processes of oxidation (as measured by the rate of evolution of carbon-dioxide), of ammonification and of nitrification in the heavy loam soils of the New Jersey Experiment Station, points out the improvement in tilth that liming has brought about in the soil of certain plots, and correlates this with the increased oxidative power of the limed soils.

2. THE EFFECT OF LIMING ON SOIL REACTION.

a. Soil acidity and plant growth.

The several inhibitory effects which an excessive concentration of hydrogen-ion in the soil solution exerts on soil conditions and plant growth have been fully discussed in the article on soil sourness already cited[21]. Perhaps the most important of these is its effect on micro-organic life. Soil acidity affects the micro-organic fauna and flora of soils in different specific ways. Whereas the bacteria and fungi that are responsible for the formation of ammonium salts from nitrogenous organic compounds present in plant residues are apparently but little affected, even by considerable acid intensity, the bacteria of nitrification and of nitrogen-fixation are very sensitive to hydrogen-ion, the activity of the latter in particular being markedly reduced by a medium whose pH value is below 6·0 ([21] p. 61). Nodule bacteria, which fix atmospheric nitrogen when they are growing in symbiosis with the roots of leguminous plants, exhibit different degrees of susceptibility to hydrogen-ion, depending on the particular strain of bacterium. The limits of acidity for the various strains that characterize different leguminous plants of cultivation vary between pH 3·15 and pH 4·9, so that nodule bacteria, on the whole, seem able to withstand a considerable concentration of hydrogen-ion in the soil solution.

Certain plant disease organisms appear to be susceptible to the toxic effect of hydrogen-ion, or conversely to that of hydroxyl-ion[21] (p. 65). Whereas a number of them can withstand an appreciably high degree of hydroxyl ion concentration, others are markedly susceptible to it.

The effect of hydrogen ion on the germination of seeds[21] (p. 61) seems to vary with the species of plant that produces the seeds, for some seeds germinate more rapidly when exposed to acid conditions, whereas others respond more readily to alkaline conditions.

The growth of plants appears to proceed best under slightly acid conditions[21] (p. 62), possibly because the absorption of ions which plants need for their nourishment is accelerated in a medium of appreciable acidity. Possibly also water absorption is controlled to some extent by hydrogen-ion concentration. Dachnowski[12] showed that water absorption is diminished by acidity, but further research is needed before any definite relationships can be finally established between the rate of water imbibition and plant growth.

b. Field experiments on liming in relation to reaction.

Numerous field experiments have been conducted in various parts of the world to test the relationship between soil reaction and the various soil processes involved in the growth of plants.

In considering the effect of lime on the different soil micro-organisms that are responsible for the several stages of decomposition that commence with the breaking down of the complex nitrogenous organic compounds present in plant residues and end in the formation of nitrates, it would be best first to consider the production of humus in soils.

(a) The extent of our knowledge as to the composition of humus and the chemical changes that are responsible for its formation from plant residues in soil is still very limited.* General experience has indicated that the maintenance of an abundant supply of humus in the soil is one of the first essentials of successful field management Thi- humus must be of the type that is formed under conditions of good aeration ; it must not contain an excess of acidic compounds or of toxic substances. The presence of lime in the soil seems to be an important factor in the complex chemical changes that are in the main controlled by micro-organic activity, and that result in the formation of a desirable kind of humus.

The rôle of lime in the soil, as a factor in humus production and in the subsequent changes that go on when humus is decomposed, is not usually clearly defined in text books on agronomy. Various statements occur to the effect that lime acts as a ' conservator ' or, *per contra*, that it acts as a destroyer of humus. The relative effects of the different forms of lime have also been discussed at great length, and numerous experiments have been described in support of one or other of the various opinions.

Frear [14], (1915, pp. 143-58) gives a detailed account of many such field experiments. His conclusions are worthy of citation. (1) ' From all the facts now in our possession humus formation and decay are due chiefly to the action of lower organisms inhabiting the soil.' (2) ' The general result of experiments is that the addition of carbonate of lime increases the rate of bacterial decomposition in the soil,' . . . . . except when this dressing is added in too large amounts.' (3) ' The effect of quicklime . . . . is a short-time decrease of bacterial and other soil life, followed ere long by a large increase in the number of these organisms and in their activity.' (4) ' Where the conditions of soil composition and reaction are such as to induce an increase

*See, however, the recent work of Beckley, *Journ. Ag. Sci.* XI, 1921, p. 69.

in bacterial life and vigour as the consequence of a lime dressing, we should expect an increased rate in humus decomposition to follow. Liming an acid soil should show such results; but liming a soil already alkaline might have little effect.' (5) 'The evidence from the more critically planned investigations does not warrant any sharp distinction between lime in the caustic (i.e. quicklime) and carbonate forms as respects their *ultimate* direct effects upon humus decay. *

Whereas these conclusions are probably true in the main various investigators have reported differences of some importance between the effects of quicklime and of calcium carbonate on the soil reaction, and consequently on micro-organic life. Thus Hutchinson and McLennan [29] have claimed that quicklime, when applied to soils brings about partial sterilization effects comparable with those produced by antiseptics and heating. In order to discover the precise chemical changes induced in the soil system through the addition of different forms of lime, Hoagland and Christie [27] followed in the laboratory the changes that went on in the hydroxyl ion concentration of three distinct types of soil, firstly after calcium oxide, and secondly, calcium carbonate, has been added to them. Hydroxyl-ion concentration was measured by the use of the hydrogen electrode. The results showed that a great increase in the hydroxyl-ion concentration occurred immediately after the addition of quicklime to all three soil types, the effect being most marked with a sandy soil. Calcium carbonate gave similar results, but much lower concentrations of hydroxyl-ion were recorded. Within three days a great decrease in alkalinity had taken place in all the soil samples. This decrease was continued slowly for more than six weeks afterwards. The investigators suggest that the partial sterilization effects which Hutchinson and McLennan observed when quicklime is added to certain soils may be due to the initial high hydroxyl-ion concentration which quicklime produces, and which is markedly toxic to many soil micro-organisms, especially protozoa. Furthermore, they point out the possibility of a deleterious effect of quicklime, if added in too great amount to soils, in that it might bring about an almost complete inhibition of nitrification.

(b) Proceeding now to a consideration of the effect of liming on the *formation of ammonium compounds* from the nitrogenous compounds present in humus, it should be remembered that ammonification is apparently not markedly depressed by acid soil conditions. It would appear that the organisms responsible for ammonification have a very wide range of acid tolerance. Nevertheless experiments have shown that liming greatly increases the production of ammonium compounds in soils. Thus Peck [49] found that lime added to sugar-cane lands in Hawaii stimulated ammonification of the soil organic nitrogen. Frear [14] (p. 137) has recorded numerous similar observations.

(c) As regarding *nitrification*, we should naturally expect

---

*Considering that quicklime is rapidly hydrated and carbonated when applied to soils (see p. 162), the specific effect of quicklime, if any, cannot be exerted for any great length of time.

liming to have a marked effect in accelerating the rate of production of nitrates from ammonium compounds in soils, for the bacteria of nitrification are very intolerant to acidity, and any decrease in hydrogen-ion concentration at once favours their multiplication. The results of an enormous number of field experiments have borne out this surmise. Noyes and Conner [48] have citied many instances where liming has been followed by increases in nitrate formation in soils. Their own experiments with typical acid soils that received dressings of calcium carbonate and of various mineral fertilizers, showed that calcium carbonate in all cases markedly increased nitrification in the acid soils, whereas fertilizers alone had little effect in this direction. Upon the same subject Frear [14] (p. 159) writes : 'It is clear that the use of lime . . . . upon an acid soil increases ammonification and nitrification. Its tendency therefore is to hasten the rate of decline in nitrogen content common to all cultivated lands, unless special methods of management, cropping* or fertilizing are used to maintain the supply.'

In connexion with the last point raised, Fred and Graul [15] found that, although liming stimulates nitrate formation at first, later the reverse is true, and that a decided decrease occurs, at least in the soils investigated by them. This result they attribute to the activity of denitrifying bacteria in the soils examined.

(d) That *nitrogen fixation* by free-living organisms in the soil is also increased by liming has been proved by Ashby at Rothamsted. Ashby [2] showed that the use of lime on certain arable soils has more than doubled the fixation of nitrogen by *Azotobacter*. Loew[38] states that liming has favourably affected *Azotobacter* development in the acid soils of Porto Rico, except where the soil texture has been such as to exclude oxygen of the atmosphere. These examples are but few from a large number of experiments on this aspect of the subject. (See Frear[14] p.141.) The results have been practically the same in all cases.

(e) Field trials on the effect of liming on the *assimilation of nitrogen by nodule bacteria* living in symbiosis with certain leguminous plants have also been carried out in recent years. Thus Lipman and Blair[35] at the New Jersey Agricultural Station have studied in the first place the effect of liming on the yield of non-leguminous plants, and have shown that limed plots lost nitrogen at a considerably greater rate than unlimed plots With leguminous plants, on the other hand, the soil of the limed plots was appreciably enriched in nitrogen as compared with the unlimed plots. This was interpreted as indicating the beneficial effect which liming produces on the activities of the nitrogen-fixing bacteria that live in symbiosis with the leguminous plants.

Fred and Graul [16] at Winconsin University also have found that the soil of limed plots growing soya beans and red clover exhibits an increase in the amount of nitrogen fixed from the atmosphere over that gained by the soil of unlimed plots.

(f) It is unnecessary to review in this article the numerous experiments that have been performed in connexion with the

*Such as the inclusion of leguminous plants in the rotation practised.

control by liming of certain *plant disease organisms* that pass, at least part of their lives in the soil. Suffice it to state that liming has long been advocated as one of the remedial measures to be tried in attempts to combat such diseases. In certain cases small dressings are apparently sufficient to limit the activities of the organisms because of their effect in reducing soil acidity. In most cases, however, large dressings are prescribed, and moreover, the form of lime to be used is definitely restricted to quicklime or slaked lime. The effects of such dressings may primarily be similar to those already described in connexion with partial sterilization of soils.

The deleterious effect on the *growth of the seedlings* of certain plants of excessive hydrogen-ion and hydroxyl-ion concentrations has been demonstrated by a limited number of nutrient culture studies to which reference has been made in the writer's article on soil sourness [21] (p. 61). Important in this connexion is the work of Hoagland [26] who found that for barley, the hydroxyl-ion is more toxic than the hydrogen-ion of the same concentration. For the nutrient solutions used, Hoagland showed that a concentration of OH-ion greater than $1{\cdot}8 \times 10^{-6}$ (pH = 8·4) was distinctly injurious, and, when exceeding $2{\cdot}5 \times 10^{-5}$ (pH = 9·5) extremely toxic to the growth of barley.

Joffe [31] adjusted the reaction of a sample of New Jersey loam soil by adding different amounts of dilute sulphuric acid or of calcium carbonate, and in this way obtained twenty soil cultures with reactions varying between pH 3·0 and 7·1. He then grew alfalfa (lucerne) from seed in each culture, and after about six months, ascertained the differences in the weights of the harvested dry crops, as well as the nitrogen percentage content of the tops. In this way he was able to demonstrate that the yield of lucerne tops showed a gradual increase with an increase in the pH value of the soil solution. Germination was found to be checked in the more acid soils, but when once established, the seedlings grew well, even in soils whose pH value was as low as 3·8. Nodule formation was least in soils of lowest pH value and correspondingly, the nitrogen content of plants grown in the more acid soils was lowest. Root development, however, was found to be greatest in the more acid soil cultures.

Quite recently, Salter and McIlvaine (see [21] p. 62), in their studies on the effect of the reaction of nutrient solutions on the germination and growth of certain commonly cultivated plants, have shown that an alkaline reaction is more harmful to these processes than an acidity reaction. There would thus appear to be actual danger in over-liming, a conclusion the force of which will further be demonstrated in another connexion. (See p. 176).

3. LIMING TO CORRECT DEFICIENCY IN CALCIUM IN CERTAIN SOILS.

The important rôle which calcium plays in plant metabolism has been discussed in some detail in the writer's article on soil sourness[21], (p. 66). It is unnecessary to reconsider the question in this place. Suffice it to state that liming is the most obviou

remedy for deficiency in calcium that may be the direct cause of the infertility of certain soils.

4. THE ANTAGONISTIC EFFECT OF CALCIUM-ION IN THE SOIL SOLUTION.

That the presence of certain salts in nutrient solutions in which plants are growing influences the specific effects produced by other salts has long been recognized. A great number of experiments have been performed to determine as definitely as possible the nature of this mutual influence, and an immense literature dealing with the results of such experiments has accumulated.

The laws governing the absorption of salts, or more strictly the absorption of ions, are little understood, and the exact mechanism whereby ions enter the plant has not as yet been definitely elucidated. It appears, however, from the researches of certain physiologists, notably Pauli, Szuces and Loeb (see [55]) that the semi-permeable membrane which separates the root cell sap from the soil solution plays a very important rôle in absorption. Various ions present in the soil solution are supposed to be able to form absorption complexes with the colloidal substances of which the membrane is composed, and by a reversal of this process, the ions enter the cell. When several ions are being conveyed into the cell by the same unit of the plasma membrane, the entrance of each is hindered by the others, and thus an antagonism arises.

As long ago as 1859, Sachs noted in nutrient culture studies that plants grow best when a certain balance is maintained between the various constituents of the solution. In 1875, Boehm observed that the toxicity produced by certain salts, when present alone in nutrient solutions, could be lessened or eliminated by small quantities of calcium salts. By numerous experiments along similar lines it has been shown that calcium-ions are able to counteract the toxic effect of an excessive concentration of such ions as those of magnesium, potassium, sodium, ammonium, barium, strontium and manganese (McCool).[40] Mutual antagonism between various combinations of pairs of these ions has also been demonstrated, and of all the elements tried, calcium-ion has been found to be the most effective in preventing injury by the action of the other ions named.

The necessity for the existence of an exact ratio between the concentrations of mutually antagonistic ions in nutrient solutions for optimum plant growth has been maintained by Osterhout[3]. Whereas recent work has in some measure borne out this assumption, it has been shown that for certain plants at least a fairly wide range in the rations of ionic concentrations is tolerated without any marked reductions in plant growth. Recent research has further indicated that the optimum ratio between ions not only varies for different plants, but also for the several growth stages of each species of plant.

Before ideas on antagonism had taken a definite form, Loew [37] elaborated a theory to account for the toxic properties of magnesium when calcium was not present in the nutrient

solution in sufficient quantity. His theory was based on the assumption that certain modifications in the chloroplasts and protoplasm of plants were produced when magnesium and not calcium was available in the nutrient solution. The theory assumes that the seat of antagonism between calcium and magnesium lies within the plant cell and not at its surface, as is nowadays generally believed. Loew considered that plants require a definite calcium-magnesium ratio for optimum growth, and assigned a value of 1.1 to this ratio in the case of cereals, with a larger proportion of calcium for other more leafy plants, This conclusion has been questioned, however, by more recent investigators.

In attempting to apply the results of nutrient solution studies on the antagonistic effects of ions on one another to the actual conditions that obtain in the soil, it is obvious that the number of influencing factors to be considered in soil studies becomes vastly greater. The components of different soils react in very different ways, when brought into contact with any given salt solution. The final balance that exists in the soil solution between the various ions derived from the compounds present in the soil, or from compounds introduced in manures and fertilizers, is the result of a highly complex series of interrelated reactions. In particular, the effects of an increased concentration of calcium-ion that follows on liming in minimizing or eliminating the toxicity due to excessive concentration of ions such as those of magnesium, sodium, aluminium and manganese, is a factor of importance in plant nutrition.

In practice, however, it is hard to gauge this effect, and although many field experiments have been devised to test the application of the principle of antagonism to actual crop production, few definite results have yet been obtained. For example, numerous investigators have sought answers to the Loew theory of a calcium magnesium ratio as applied to soils and liming, with just as numerous and conflicting results. A review of the work of the more noteworthy of these attempts is given by Wyatt,[58] whose own experiments with certain cereals and leguminous crops, grown in various types of soil to which different kinds and amounts of calcium and magnesium compounds were added, indicate that ratios of calcium to magnesium within rather wide limits give no marked differences in yield. There would appear, therefore, to be little fear of injury attached to the use of low-grade potash fertilizers rich in magnesium salts, or of magnesian limestone as soil ameliorants, which is against the view previously held by many agronomists (see [14], pp. 191-201).

A recent investigation by Greaves[19] is worthy of record. This worker attempted to discover the extent of the antitoxic action of various calcium and iron salts towardsother compounds, when applied to a typical Utah arable soil. Solutions of the salts were added to the soil in definite amounts, and the effects on ammonification and nitrfiication were quantitatively estimated. The multiplicity of results is too great to be recorded in full in this place, but it may be mentioned that indications were obtained that the non-metallic ions, as well as the metallic ions yielded by the salts, exerted antagonistic effects one on the

other. Calcium-ion was especially found to be antitoxic to various other ions, at least so far as ammonification and nitrification are concerned.

Although Greaves' work does not throw further light on the direct relationship in the soil between antagonism and absorption by the roots of higher plants, yet it has some bearing on the question of fertility, and on this account is worthy of mention.

5 THE EFFECT OF LIMING IN PRECIPITATING CERTAIN TOXIC ORGANIC AND INORGANIC SUBSTANCES IN THE SOIL SOLUTION.

(a) *Precipitation of toxic organic substances.*

The widely-discussed question of the rôle which certain complex toxic organic substances play in soil infertility has led to a reconsideration of the mechanism of the action of fertilizers. Those who hold that infertility is due, in the main, to the presence in soils of toxic organic compounds, ascribe the beneficial effects of manuring to its ability to counteract these toxins. In particular it has been demonstrated by culture experiments that calcium carbonate is an effective agent in decreasing the toxicity of certain organic compounds.

Thus Breazeale[6] in 1906, and Livingston[36] in 1907 showed that water extracts of certain unproductive soils were greatly improved by the addition of calcium carbonate, and were thereby rendered capable of supporting healthy plants. Schreiner and Skinner (see[21], p. 76) found that toxicity of salicylic aldehyde to wheat seedlings growing in nutrient media was decreased by the addition of calcium carbonate to the cultures. Many other investigators have demonstrated that the deleterious effect on plant growth of certain acidic products of the decay of plant residues and of definite root excretions may be counteracted by neutralizing the culture media containing these substances with calcium carbonate (see[21], [76] Rigg; Dachnowski).

The mechanism of the antitoxic effect of calcium carbonate in many of the experiments described in the literature on the subject, both those in which nutrient culture media and those in which actual soils were used, is not in every case quite clear. In those instances where the toxic organic compound is a definite acid, such as dihydroxystearic acid, it is easy to understand that neutralization by means of lime might give rise to a harmless calcium salt or to an insoluble product which is incapable of being absorbed by plant roots. Probably the beneficial effects ascribed to the direct chemical action of calcium carbonate, especially in connexion with actual soils, are in reality due to the general improvement of the environmental conditions, in that the oxidative power of the medium is increased by the addition of lime, or the development of bacteria responsible for the destruction of the toxic compounds is encouraged.

(b) *Precipitation of toxic inorganic substances.*

It was noted by Ruprecht and Morse[52] in their culture studies with aluminium and iron sulphates, that the addition of calcium carbonate to the cultures eliminated the toxic effect

of the ions of these metals. This result they explained as being due to the removal of the toxic metallic-ions by their precipitation as hydroxides.*

Mirasol[45] in his comprehensive investigation into the significance of aluminium as a factor in soil sourness (see[21], p.70), also demonstrated the antitoxic effect of calcium carbonate when introduced into sand cultures of clover which were treated with solutions of salts of aluminium. Mirasol, however, considered that the calcium carbonate precipitated the aluminium, not as hydroxide, but as the much more insoluble calcium aluminate.† Similar results were obtained when calcium superphosphate (acid calcium phosphate, $CaH_4(Po_4)^2$), was substituted for calcium carbonate, but in this case it was assumed that the precipitation of the active aluminium is due to the formation of insoluble aluminium phosphate.‡

The removal of aluminium from the soil solution by liming (or phosphating), which may be assumed to take place in those cases where an excessive concentration of aluminium-ion occurs must be carefully distinguished from the antagonistic effect that calcium-ion exerts in minimizing the absorption of aluminium-ion by the plant root, as described in the last section.

In the majority of cases of sour soils that contain an excessive concentration of aluminium-ion in the soil solution, the effect of increasing the amount of dissolved bicarbonate by adding lime to the soil is primarily to precipitate the aluminium. Simultaneously and collaterally with this, the increased concentration of calcium-ion opposes the entry of aluminium-ion into the plant root cells. This latter effect may obviously only become significant when the aluminium-ion concentration reaches a low figure.

As regards iron and manganese, liming may confidently be expected to remove excess of the former when it occurs in high concentration in the soil solution, for the properties of iron compounds are very similar to those of aluminium compounds. In the case of maganese, Mirasol (*loc. cit*) found that calcium carbonate introduced into sand cultures treated with solutions of manganese salts had little effect in precipitating the metal††

(c) *Effects of an excessive lime content in soils.*

It is possible to imagine that an excessive concentration in the soil solution of calcium bicarbonate, and of the ions yielded by this compound when it dissociates, might precipitate practically completely all the aluminium and iron that is present in solution. Since all plants require iron as an element essential

*$3\,Ca(HCO_3)_2 + Al_2(So_4)_3 + 6H_2O = Al_2(OH)_6 + 3\,Ca\,So_4 + 6H_2\,CO_3$

†$4\,Ca(HCO_3)_2 + Al_2(SO_4)_3\,C\,4\,H_2\,O = Ca\,O.\,Al_2\,O_3 + 3\,CaSO_4 + 8H_2CO_3$

‡$Ca\,H_4\,(PO_4)_2 + Al_2\,(SO_4)_3 = 2AlPO_4 + Ca\,SO_4 + 2H_2\,SO_4$.

††Numerous investigations have been carried out on the toxicity to plant growth of such inorganic substances as salts of copper and arsenates (see Trom and Sykora, *Soil Science*, III, 1907, p.333). They are not of sufficient general importance to warrant record in this article.

to the production of chlorophyl, it might follow that the almost complete precipitation of iron by calcium carbonate, coupled with a marked antagonism to its entry into the root cells, wolud result in some functional derangement which would become symptomatic in plants growing under such special conditions. That this result does actually happen when a soil contains a great excess of calcium carbonate is indicated by recent researches into the causes of lime-induced chlorosis in plants.

Plants growing in soils very rich in calcium carbonate frequently are characterized by a yellow or pale-green leaf-colour which stands out in marked contrast to the dark-green tint normally exhibited by the plants. Thus grape-vines growing on certain limestone soils in France often show this peculiarity, and sugar-cane, rice, maize and other cereal grasses, pine-apple, pear, apple and citrus fruit trees also exhibit similar appearances associated with the same soil condition. The name 'chlorosis' has been given to the affection. There are other causes of chlorosis, besides the one already mentioned, but these will not be discussed in this place.

Plants that suffer from lime-induced chlorosis frequently contain in their leaves abundant crystals of calcium oxalate. Despite the removal of large amounts of calcium from the plant sap thus indicated, the sap is neutral or alkaline in reaction instead of normally slightly acid. At first sight therefore, lime-induced chlorosis would appear to be the result of excessive alkalinity in the plant sap produced by over absorption of calcium-ion.

Gile and Carrero[18], in a critical study of the cause of lime-induced chlorosis in certain plants, showed, however, by analysing the ash of chlorotic leaves, that a deficiency in iron is usually associated with the chlorotic condition, with possibly an excess of calcium as a contributing factor. Chlorosis was found to be remedied to some extent by spraying the leaves of chlorotic plants with iron sulphate solution. Numerous experiments with the rice plant indicated that rice is not very sensitive to the presence of excessive amounts of calcium carbonate in the soil, but is markedly sensitive to depression in the availability of iron which such excess produces.

Although the causal relationship between calcium carbonate and the low availability of iron in soils containing excess of lime is indicated by Gile and Carrero's investigations as the major factor in certain examples of chlorosis, the simple explanation of the precipitating and antagonising effect which lime exerts on iron in nutrient solutions as described above apparently does not completely fit the case when applied to actual soil conditions. Gile and Carrero showed that the presence of organic matter in soil in some way affects the availability of iron in highly calcareous soils, as does also the presence of free water and clay substance. The whole question is therefore one of considerable complexity. It may at least be concluded that liming may become a real danger if carried too far, especially in the case of dry sandy soils not over rich in organic matter.

6. THE POSSIBLE INDIRECT FERTILIZING EFFECT WHICH LIME MAY BRING ABOUT IN CAUSING AN EXCHANGE OF IONS WHEN ADDED TO SOILS.

The effect which liming produces on the water soluble nutrients of soils has been the subject of a great deal of experimentation. The prevailing idea has been that liming renders more available certain elements, such as potassium, magnesium, and the phosphate radicle, because of the interchange of ions that is presumed to go on between the added lime and certain mineral components of soils*. Certain experiments, however, seem to refute this theory.

(a) *Potassium.*

Let us first consider the case of potassium. Several laboratory experiments on the effect of lime on potassium-bearing minerals, such as orthoclase felspar, have been carried out by various investigators. Thus Brigg and Breazeale[7] found that powdered orthoclase, as well as soils containing this mineral, caused no increase in water soluble potassium, when shaken with a solution of calcium carbonate on several soil-forming minerrals The results of his experiments show that calcium bicarbonate solution possesses no power to unlock potash from any of the minerals tried.

Whilst the majority of experimenters have obtained results concordant with the above, Morse and Curry[4 6] found that lime increased the solubility of potassium in felspar, but that this effect may not be observed when soils are similarly treated, because of the simultaneous removal of the liberated potassium, owing to the adsorbtive power of colloidal clay.

Andrè[1] noted that glauconite (a hydrated silicate of aluminium iron and potassium), yields part of its potassium when treated with calcium carbonate.

Theoretically, by the principle of basic exchange, it is possible that salts of calcium, including the bicarbonate, might react with potash minerals so as to liberate potassium-ions to the soil solution. According to the adsorption idea of basic exchange, the calcium-ions set free by dissociation of a neutral calcium salt added to soil are absorbed by certain soil colloidal substances, and the free acid is liberated. (See[2 1], p. 67.) This acid is then able to attack potassium-bearing minerals, and thus to bring about an increase in the potassium-ion concentration in the soil solution. It is conceivable, however, that carbonic acid (which is the acid corresponding to calcium bicarbonate) is too weak an acid and is liberated in too small amount to decompose the commoner potassium-bearing minerals in the soil, so that one is able to explain in this way the negative results obtained by the majority of investigators who have studied the reaction between lime and certain potash minerals.

Bradley[5] showed that lime did not act as an indirect fertilizer when applied to soils in the laboratory, although gypsum gave an increase in the water-soluble potassium of the extracts

*See for example, Hall, 'TheSoil.' LondonMray ,"Johur1918, p. 262. Also Hilgard, "Soils.n ,New York. Mcamillan, 1918, p. 379.

Christie and Martin[8] set out to discover by a series of laboratory experiments possible reasons for the apparent disagreement between investigations on the question of the indirect fertilizing action of lime. They studied the chemical effects of calcium oxide and of calcium carbonate on the water-soluble nutrients of several soils belonging to three distinct types Water extracts of the limed and unlimed soils were analysed, and the amounts of calcium, magnesium, potassium, phosphate, sulphate and nitrate were compared in them at various periods. Supplementary data by freezing point and electrical conductivity methods were also obtained. The results of this research show that all soils do not react chemically with lime in the same manner, and further, that even the same soil under different concentrations of soil solution, due to cropping or fallowing, may react differently. It is difficult to understand the reason for these facts; evidently the addition of lime changes the equilibrium in the soil solution, and the resultant effects are variable. It would thus appear to be impossible to predict what the effects of liming will be as regards increasing or decreasing the availability of nutrient elements in any particular soil. Only actual trials with the soil in question could be hoped to yield definite information as to these effects.

As an interesting example of an extensive investigation into the effect of liming on the availability of potassium under field conditions, the work of Mc Intire[44] at the Pennsylvania Experiment Station in 1911, and at the Tennessee Station in 1914-19, is worthy of record. McIntire tabulated a number of systematic analyses of the leachings that collected in lysimeters into which the water from two types of limed soils contained in large tanks was allowed to drain. The results showed that the original free soil-water leachings were richer in potassium salts than they were when they become impregnated with calcium bicarbonate. No indications were obtained to suggest that lime so altered the original form of the soil-potassium as to render any portion of it more available or beneficial to plant growth.

These results are in perfect agreement with those of earlier but similar studies undertaken by Lyon and Bizzell[39] at the Cornell University Experiment Station, and coincide in general with the findings of many other workers in various parts of the world. In certain cases, noteworthy exceptions have been recorded in which liming has been found to increase the potassium content of the soil solution. These exceptions are in most instances susceptible of elucidation by considerations of local peculiarities of rainfall, soil-type cropping or temperature-range, all of which must have their bearing on the extent of the potassium outgo from the soil.

The chemical analyses of wheat furnished by Gaither[17] and by McIntire[41] indicate a depressing effect on the absorption of potassium when wheat crops are grown on limed soils. This result has also been noted by other investigators for other species of silicicolous plants, and it has long been known that such plants respond most markedly to potassic manures when growing on soils rich in calcium carbonat

(b) *Phosphates.*

As regards the effect of lime on phosphates in the soil, it appears from numerous experiments that there is some possibility of lime increasing the availability of this important soil component under certain specific conditions. Thus Hartwell and Kellog [22] found that liming considerably increased the yield of turnips at the Rhode Island Experiment Station, and that the percentage of phosphorus in the dry-matter of these plants was greater than in that of turnips grown in unlimed soil.

The Rhode Island soils, however, are markedly acidic in reaction, and contain appreciable excess of aluminium and iron-ions in the soil solution. It appears probable in this case, and in most other similar cases, that the beneficial effect of liming is due to the interaction between the lime and the aluminium and iron phosphates present in the soil. As a result of this action, the very insoluble compounds, calcium aluminate * and calcium ferrate, are probably formed in some amount, with the consequent production of the more readily soluble calcium phosphate. Thus in adding phosphatic manure to calcium-deficient sour soils, lime should first be applied to precipitate aluminium and iron.

It is interesting to note in this connexion, that dicalcium silicate (Ca_2SiO_4), an artificial product obtained by leaching a mixture of natural rock silicates, has been found equally as effective as calcium carbonate in correcting soil sourness due to excessive concentration of aluminium-ion in the soil solution [24]. It has already been sta'ed (p.176) that calcium superphosphate acts in a similar manner.

III. The Lime Requirements of Soils.

In order to obtain definite information as to the quantity of lime that might be required to bring a given soil into a more suitable condition for crop growth, soil scientists have long been striving to elaborate experimental methods for determining lime requirements of soils. Until recently it was firmly believed that the necessary condition of a soil for optimum plant growth is a condition in which the soil is fully saturated with lime. By this was really implied that a soil, in order to be highly productive, should possess a neutral or slightly alkaline reaction, acidity being thought in all cases to be detrimental to plant growth.

In order to illustrate the methods whereby soil scientists have attempted to measure the lime requirements of soils, a few typical examples will briefly be described.

1 The Tacke Method.

One of the earliest methods elaborated for estimating lime requirements is that due to Tacke† (1897). It consists essentially

---

* See p. 176 Mirasol [12].

†Chem.-Zeitung, 20, 1897, p. 174

in shaking together for a specified length of time soil and finely divided calcium carbonate in weighed portions, both previously made into thin pastes with water, and allowed to react upon one another in an atmosphere of hydrogen. The liberated carbon dioxide is determined, and thus the quantity of calcium carbonate which has been decomposed by the soil acids is found. This is taken as a measure of the lime required to correct soil acidity.

2. THE VEITCH METHOD.

A much more widely used method is that due to Veitch* (1902). A solution of calcium hydroxide of known concentration is added in varying amounts to unit quantities of the soil under examination until that proportion of lime-water to soil is found where the mixture, after being boiled down to dryness and then extracted with water for twenty-four hours, gives a neutral reaction to phenolphthalein. This method, besides taking into account the lime needed to neutralize soil acidity, also allows for the lime absorbed in other processes, such as the flocculation of colloidal particles.

3. THE HUTCHINSON—McLENNAN METHOD.

This method, as described by its inventors in 1915†, differs from the last two in that a solution of calcium bicarbonate of N/50 concentration is used instead of a solution of an alkaline-earth hydroxide. In this respect it therefore more nearly represents the liming of soils, in which calcium bicarbonate, as has been shown in another place, is the active agent. The soil is shaken with the bicarbonate solution for an arbitrary length of time (three hours is specified). The amount of lime absorbed is estimated by noting the differences in the readings obtained by titrating separately a certain volume of the filtered solution, and an equal volume of the initial bicarbonate solution against N/10 acid using methyl orange as indicator.

4. THE BOUYOUCOS METHOD.

Bouyoucos in 1916†† suggested a method which only differs essentially from the one proposed by Veitch in that the end point of the reaction between soil and lime-water is found by freezing point determinations.

5. THE ELECTROMETRIC METHOD.

Sharp and Hoaglan‡ (1916) have examined the possibility of using the hydrogen-electrode for estimating the lime requirement of soils. To the mixture of soil and water in the reaction

---

Journ. Amer. Chem. Soc. 24, 1902, p. 1120. See also Watts[56] for full details and a discussion of the method.

†*Journ. Agric. Sci.*, VII, 1915, p. 75. See also Watts[56].

††Mich. Agric. Expt. Sta. *Tech. Bull.* 27, 1916. See also Watts[56] for a full discussion of the method.

‡*Journ. Agri. Res.* VII, 1916, p. 123.

vessel, a standard solution of calcium hydroxide is added, until a definite alkaline reaction is obtained corresponding to pH values above 7·0 In this way the amount of lime needed to impress any desired degree of alkalinity under the conditions of the experiment can be ascertained.

Knight* (1920) performed a similar experiment in which he recorded the change in potential of the hydrogen electrode immersed in a suspension of an acid soil on shaking the suspension with a solution of calcium hydroxide. He found in another experiment† that the addition of a neutral salt to the mixture of soil and lime greatly increased the speed of reaction between the soil acids and the base.

6. THE COLORIMETRIC SYSTEM. (See[21] p. 54.)

An attempt was made by E. A. Fisher‡ to measure lime requirement by adding varying amounts of base (barium hydroxide was chosen) to a series of mixtures of soil with twice its weight of water, shaking for an hour and then measuring the pH value colorimetrically after centrifuging. By plotting the values of interpolating at pH = 7·0 (i e neutrality), the amount of lime required to bring the reaction of the soil to neutrality under the conditions of the experiment could be calculated.

Numerous investigators‡‡ have at different times compared the above and other methods for measuring lime requirements of soils, and have found that the variations introduced in the procedure, and the difficulties experienced in the final measurement of the end-point lead to very considerable discordance in the values obtained.

It has been shown, for instance, that the degree of subdivision[13] of the soil used in the lime requirement estimation; the chemical nature and state of the base [52], [53] or the concentration of the basic solution added[13]; the length of time allowed for the interaction between soils and base[13]; the effect of shaking; the temperature [51] [53]; the presence or absence of a neutral salt[52]; and the physical type of soil examined[13], each plays a part in deciding the final result.

Possibly the chief reason for many of the inconsistencies in the recorded experimental data lies in the fact that soil acids, whatever be their nature, vary greatly in activity, and are formed continuously in the soil at rates depending upon numerous interrelated factors, such as the degree of soil aeration and soil moistness, the extent to which leaching and absorption

---

Journ. Ind. Eng. Chem., XII, 1920, p. 463 [32].
†Ibid. p. 461.
‡*Journ. Agric. Sci.*, XI, 1921, p. 57 [13]
‡‡For example :—
Schollenberger. *Soil Sci.*, III, 1916, p. 279,
Christiansen, *Soil Sci.*, IV, 1917, p. 115.
Bear, *Soil Sci.* IV, 1917,, p. 433.
Stephenson (53),
Knight (32),
Robinson (53),
Fisher (13),

by plants go on, and the action on the soil of added fertilizers. Thus under varying environmental conditions the complex soil components yield hydrogen-ions to the soil solution at correspondingly varying rates. The numerous actions and reactions involved, however, tend slowly toward the establishment of a condition of equilibrium. The introduction of lime into the system of soil and plant upsets this balance, and time is needed for the equilibrium condition again to become established. The fact that liming, apart from neutralizing soil acidity, also has an effect in bringing about important changes in the degree of dispersion of the colloidal particles in the soil[13], and in reacting with certain inorganic compounds, such as iron and aluminium-bearing minerals, further complicates matters, for in certain cases a considerable proportion of the added lime may be used up in these processes.

In most instances the extent of the time factor cannot easily be gauged. Experimental evidence points to its duration as being measurable only in months, or even years. It is not to be wondered, therefore, that laboratory methods for estimating the lime requirements of soils have so far proved to be of no very great practical value, or that it should seem impossible to elaborate some method which would be entirely satisfactory.

On the other hand, lime requirement methods have their uses in that they supply the investigator with some evidences as to the causes of acidity in particular soils, especially when the results obtained by their employment are considered along with other data, such as hydrogen-ion concentration of the soil solution and the degree of colloidality of the soil. Information gained from their application to soils also furnishes a basis for outlining and prosecuting field trials, and for this reason alone, lime requirement determinations will always be of some value to the agronomist.

As instances of the correlation between laboratory evidence and field practice in this connexion, the following examples may be noted.

McIntire[42] observed that when calcium carbonate is applied to soils in excess of the amount found by laboratory experiments to be necessary to bring the soil to a neutral reaction, the excess of lime gradually disappeared, demonstrating the existence of a long-continued reaction between soil and lime. Hoagland and Christie[27] record similar results.

Stewart and Wyatt[54] found that the neutralization of soil acidity, brought about by applying lime to soil plots at the Illinois Agricultural Station, was a very slow process, due in part at least to mechanical difficulties in mixing the lime into the soil, and to the coarseness of the material used. Even after three and a half years the acidity of certain soils had not been neutralized, though heavy lime dressings had been applied.

Blair and Prince[4], in their studies of the limed plots at the New Jersey Agricultural Station, attempted to correlate lime requirement, as measured by the Veitch method, with hydrogen-ion concentration of the soil extract. They found that the

decreases in lime requirement were not altogether proportional to the amounts of lime added. Some positive relationship was discovered between lime requirement and hydrogen-ion concentration, and it was found possible to assign in most cases a fairly definite lime requirement figure to a given pH value. Joffe [30], at the same station, observed that, with sandy soils low in organic matter and exhibiting little buffer action, an adjustment of reaction based on quantitative indications given by hydrogen-ion determinations may be accomplished by liming.

IS SOIL NEUTRALITY ALWAYS ESSENTIAL FOR OPTIMUM PLANT GROWTH?

Two other investigations are worthy of note in connexion with the much debated question of the relation between soil fertility and reaction. Cook and Allison[10], in pot culture experiments on the growth of buckwheat in lime acid soils of three types, found that a small application of lime produced nearly as large a crop yield on sandy loam and silt loam soils receiving ammonium sulphate as did larger amounts; and even better results in the case of sandy soils. Where large amounts of lime were applied at one application, it appeared that considerable unnecessary loss might be experienced in the cultivation of buckwheat. Buckwheat grown in the more acid soils showed a higher nitrogen content but a somewhat smaller yield of crop than buckwheat grown in neutralized or alkaline soils; the recovery of nitrogen from the acid soils was evidently as great as, or even greater than, that from neutral or alkaline soils. These results were interpreted as implying that buckwheat is able either to take up its nitrogen as ammonia (which has been shown, however, by previous nutrient culture experiments, not to be a common faculty of this plant), or else nitrification proceeds to a considerable extent in the presence of acids.

Hartwell and Pember[23] noted in field experiments conducted at the Rhode Island Station that, under conditions where liming exerted very little influence upon the growth of rye, barley was increased two to threefold. Evidently these two crops are affected differently by acid soil conditions. Investigations with nutrient water and sand cultures of rye and of barley were inaugurated in order to test this conclusion. It was found that a given amount of acidity artificially created by adding sulphuric acid to the nutrient media produced approximately equal effects on the growth of rye and barley seedlings. Hence an excessive concentration of hydrogen-ion is not the limiting factor to growth in the case of barley rooted in soils of acid reaction at the Rhode Island Station. Numerous other possible inhibiting factors were examined, and by a process of elimination, it was finally proved that an excessive concentration of aluminium-ion in the soil solution was responsible for the different influence of these acid soils on the crops mentioned. Whereas rye can withstand considerable concentration of aluminium-ion in the soil solution, barley is eminently sensitive to it. Liming therefore increases the productivity of the Rhode Island soils to barley, mainly because it precipitates active

aluminium in the soil solution. Superphosphate* was found to have similar beneficial results for the same reason, even despite the fact that its use appreciably increased the acidity of the soil growing the barley crop.

This instance has been considered in some detail because it furnishes an excellent example of the fallacy in the statement that liming in all cases is a positive remedy for that type of infertility that is usually associated with an acid soil condition. Doubtless many other examples exist amongst the commonly cultivated crops†, and detailed investigation is urgently needed in order to settle definitely, which of the factors known to be associated with an acid reaction is fundamentally responsible for the low productivity of certain sour soils growing specific crops.

The indiscriminate use of lime is to be condemned almost as strongly as a neglect to employ it in those particular cases where beneficial results can positively be expected to follow, and where economic reasons do not entirely prohibit its inclusion amongst the soil amendments regularly purchased.

The numerous data adduced in this paper and in the author's article on soil sourness[21] indicate that soil acidity, *per se*, is not always an objectionable condition which invariably requires an application of lime for its correction. In fact, soil acidity may in certain instances be beneficial in controlling plant diseases, or in preventing malnutrition. Workers in the United States have long been aware of these facts, indeed Coville[11] in a recent official bulletin has evolved a rational system of acid land farming based on the selection of acid tolerant crops to be grown in rotation, which promises great economic returns to those who are concerned in the cultivation of the vast areas of sour soil that exist in parts of the United States.

It has even been advocated that in certain specific cases, for example, the cultivation of scab-free potatoes, a definite degree

---

*So too was dicalcium silicate[24].

†In particular reference to the West Indies, attention is drawn to the statements made by Watts[56] (pp. 340-1).

(a) *Cacao.* 'In the many experiments that have been made in adding lime to the soil of cacao orchards, it has seldom resulted that the crop has been markedly increased'

(b) *Limes.* 'The evidence from Dominica and other West Indian islands shows that lime trees will flourish on soils containing remarkably small quantities of carbonate of lime.

The writer has been able to verify this latter statement by his own observations in Dominica. It would seem possible that many West Indian soils, derived from volcanic rocks and frequently exhibiting markedly acid reaction, might contain excessive concentrations of aluminium-ion in the soil solution. The fact that lime trees, and indeed most of the common West Indian crops (Watts, *loc. cit.*, p. 340) apparently thrive quite satisfactorily in such soils, would seem to indicate that these plants possess considerable tolerance to aluminium. This supposition requires to be tested experimentally, however, and there is need for detailed investigation into the degree of tolerance to aluminium and to other toxins that the various West Indian cultivated plants exhibit. This done, it would then be possible to offer more definite advice as to the desirability of liming, or at least, as to the necessity for field trials on the liming of these plants in the West Indies.

of acidity should be impressed on an otherwise neutral or alkaline soil by the use of sulphur or some other acid-yielding substance.[34] (See also[31], pp. 65 and 66.)

There is obviously much need for further investigation along the lines indicated in this article, not only in the laboratory, but also in the field, for liming must in future be looked upon as an exact operation to be performed only when accurate information regarding the significance of the various factors that might be involved in its employment has been accumulated for any particular soil, and for any particular crop.

Bibliography.

1. André, G. Displacement of the potash and phosphoric acid content of certain rocks and some fertilizers. *Compt. Rend. Acad. Sci.* Paris, t. 162, 1916, p. 133.
2. Ashby, S. F. Some observations on the assimilation of atmospheric nitrogen by Azotobacter. *Journ. Agri. Sci.* II., 1907, p. 35.
3. Atkins, W. R. G. Some recent researches in plant physiology. London. Macmillan, 1916.
4. Blair, A. W. and Prince, A, L. The lime requirement of soils compared with H-ion concentration of the soil extract. *Soil Science*, IX, 1920, p. 253.
5. Bradley, G. E. Reaction of lime and gypsum on some Oregon soils. *Journ. Indus. Eng. Chem.* II, 1910. p. 529.
6. Breazeale, J. F. Effect of certain solids upon the growth of seedlings in water cultures. *Bot. Gaz.*, 41, 1906, p. 54.
7. Briggs, L. J. and Breazeale, J. F. Availability of potash in certain orthoclase-bearing soils as affected by lime and gypsum. *Journ. Agr. Res.* VIII, 1917, p. 21.
8. Christie, A. W. and Martin, J. C. The effects of CaO and $CaCo_3$ on the soil. II. The effect on water-soluble nutrients in soils. *Soil Science*, V, 1918, p. 383.
9. Comber, N. The flocculation of soils. *Journ. Agr. Sci.*, X, 1920, p. 425.
10. Cook, R. C. and Allison, F. E. The effect of soil reaction on the availability of ammonium sulphate. *Soil Science*, III, 1917, p. 487.
11. Coville, F. V. The agricultural utilization of acid lands by, means of acid tolerant crops. U. S. Dept. *Agr. Bull.*, 6, 1913.
12. Dachnowski, A, The effects of acid and alkaline solutions upon the water relation and the metabolism of plants. *Amer. Journ. Bot.* I, 1914, p. 412.
13. Fisher, E. A. Studies on soil reaction. *Journ. Agr. Sci.*, XI, 1921, p. 19.
14. Frear, W. Sour Soils and Liming. Penn. Dept. Agr. *Bull.* 261, 1915.

15 Fred, E. B. and Graul, E J. Some factors that influence nitrate formation in acid soils. *Soil Science*, I, 1916, p. 317.

16. Fred, E. B. and Graul, E. J. The effect of inoculation and lime on soy beans. *Soil Science*, VII, 1919, p. 455.

17. Gaither, E. W. The effect of lime upon the solubility of the soil constituents. *Journ. Indus. Eng. Chem.* II, 1910, p. 315.

18. Gile, P. L. and Carrero, J. O. Cause of lime-induced chlorosis and availability of iron in the soil. *Journ. Agric. Res.*, XX, 1920, p. 33.

19. Greaves, J. E. The antagonistic action of calcium and iron salts towards other salts as measured by ammonification and nitrification. *Soil Science*, X, 1920, p. 77.

20. Hall, A. D. and Morison, C. G. T. The flocculation of turbid liquids by salts. *Journ. Agr. Sci.*, II, 1907, p. 244.

21. Hardy, F. Soil sourness, its meaning and significance. *West Indian Bull.* XIX, 1921, p. 37.

22. Hartwell, B. L and Kellog, J. W. On the effect of liming upon certain constituents of a soil. Rhode Is. Agr. Expt. Sta. 18th Annual Rept., 1905, p. 242.

23. Hartwell, B. L and Pember, F. R. The presence of aluminium as a reason for the difference in the effect of so-called acid soil on barley and rye. *Soil Science*, VI, 1918, p. 259.

24. Hartwell, B. L. and Pember, F. R. The effect of dicalcium silicate on an acid soil. *Soil Science*, X, 1920, p. 57.

25. Hartwell, B. L., Pember F. R., and Howard, L. P. Lime requirements as determined by the plant and by the chemist. *Soil Science*, VII, 1919, p. 279.

26. Hoagland, D. R. The effect of H and OH-ion concentration on the growth of barley seedlings. *Soil Science*, III, 1917, p. 547.

27. Hoagland, D. R. and Christie, A. W. The chemical effects of CaO and CaO_3 on the soil. I. The effect on soil reaction. *Soil Science*, V, 1918, p. 379.

28. Hutchinson, H. B. The partial sterilization of the soil by means of caustic lime. *Journ. Agri. Sci.*, V, 1913, p. 320.

29. Hutchinson, H. B. and McLennan, K. The relative effect of lime as oxide and carbonate on certain soils. *Journ. Agr. Sci.*, VI, 1914, p. 302.

30. Joffe, J. S. H-ion concentration measurements of soils in connexion with their lime requirements. *Soil Science*, IX, 1920, p. 261.

31. Joffe, J. S. The influence of soil reaction on the growth of alfalfa. *Soil Science*, X, 1920, p. 301.

32. Knight, H. J. Acidity and acidimetry of soils. *Journ. Indus. Eng. Chem.*, XII, 1920, pp. 340, 457 and 559.

33. Kopeloff, N. The influence of fineness of division of pulverized limestone on crop yield, etc. *Soil Science.* IV, 1917, p. 19.

34. Lipman, J. C. Adjusting the soil reaction to the crop. *Soil Science*, VII, 1919, p. 181.
35. Lipman, J. C. and Blair, A. W. The lime factor in permanent soil improvement. I. Rotations without legumes. II. Rotations with legumes. *Soil Science*, IX, 1920, p. 83.
36. Livingston, B. E. Further studies on the properties of unproductive soils. U.S. Dept. Agr. Bur. Soils. *Bull.* 36, 1907.
37. Loew, O. 'Flora', Band 75, 1892, p. 368.
38. Leow, O. Porto Rico Agr. Expt. Sta. *Bull.* 13, 1913.
39. Lyon, T. L. and Bizzell, J. A. Calcium, magnesium, potassium and sodium in the drainage water from limed and unlimed soil. *Journ. Amer. Soc. Agron.* VIII, 1916, p. 81.
40. McCool, M. M. The action of certain nutrient and non-nutrient bases on plant growth. Cornell Univ. Agr. Expt. Sta. *Mem.* 2, 1913, pp. 115-216.
41. McIntire, W. H. The influence of fertilizers upon the composition of wheat. Penn. Agr. Expt. Sta. Rept:, 1911.
42. McIntire, W. H. Factors influencing the lime and magnesium requirements of soils. Tenn : Agr : Expt : Sta : *Bul* : 115, 1916.
43. McIntire, W. H. The carbonation of burnt lime in soils. *Soil Science*, VII, 1919, p. 325.
44. McIntire, W. H. The liberation of natural soil potassium. *Soil Science*, X, 1920, p. 337.
45. Mirasol, J. J. Aluminium as a factor in soil acidity. *Soil Science*, X, 1920, p. 153.
46. Morse, F. W. and Curry, B. E. The availability of soil potash in clay and clay loam soils. N. H. Agr. Expt. Sta. *Bull.* 142, 1909, p. 39.
47. Neller, J. R. The oxidizing power of soil from limed and unlimed plots. *Soil Science*, X, 1920, p. 29.
48. Noyes, H. A. and Conner, S. D. Nitrates, nitrification and bacterial contents of five typical acid soils as affected by lime, etc. *Journ. Agr. Res.*, XVI, 1919, p. 27.
49. Peck, S. S. Hawaiian Sugar Planters' Station, *Agr. and Chem. Bul.* 34.
50. Plummer, J. K. Availability of potash in some common soil forming minerals. *Journ. Agr. Res.*, XIV, 1918, p. 297.
51. Robinson, R. H. The effect of heat on the reaction between lime water and acid soils. *Soil Science*, IX, 1920, p. 151.
52. Ruprecht, R. W. and Morse, F. W. The effect of sulphate of ammonia on soil. Mass. Agr. Expt. Sta. *Bull* : 165, 1915.
53. Stephenson, R. E. Soil acidity methods. *Soil Science*, VI, 1918, p. 33.
54. Stewart, R. and Wyatt, F. A. The comparative value of various forms of limestone. *Soil Science*, VII, 1919, p. 273.

55. Stiles, W. and Jorgensen, I. The antagonism between ions and the absorption of salts by plants. *New Phytologist*, XIII, 1914, p. 253.

56. Watts, F. The liming of soils. *West Indian Bull*, XVI, 1917, p 332.

57. Wolkoff, M. I. Studies on soil colloids. I. Flocculation of soil colloidal solutions. *Soil Science*, I., 1916, p. 585.

58. Wyatt, F. A. Influence of calcium and magnesium compounds on plant growth. *Journ. Agr. Res.*, VI, 1916, p. 589.

STUDIES IN WEST INDIAN SOILS.

II. THE SOILS OF MONTSERRAT, THEIR NATURAL HISTORY AND CHIEF PHYSICAL PROPERTIES, AND THE RELATIONSHIP OF THESE TO THE PROBLEM OF DIE-BACK OF LIME TREES.*

BY F. HARDY,

Chemist, Imperial Department of Agriculture for the West Indies.

INTRODUCTORY.

PART I. THE NATURAL HISTORY AND CHIEF PHYSICAL PROPERTIES OF THE SOILS OF MONTSERRAT.

(A) The Geology and Topography of Montserrat.

(B) The Main Soil Types of Montserrat.

(1) Talus Soils.

(2) Shoal Soils.

(a) Humid Upland soils.

(b) Hilly-land soils.

(c) Valley soils.

(C) The Climatic Conditions in Montserrat.

PART II. THE RELATIONSHIP BETWEEN CERTAIN SOIL FACTORS AND DIE-BACK OF LIME TREES.

(A) The problem of Die-back of Lime Trees in Montserrat.

(B) Soil conditions in relation to Die-back.

PART III. METHODS USED IN THE SOIL INVESTIGATION.

SUMMARY.

LIST OF REFERENCES.

*Received for publication January 1, 1922.

INTRODUCTORY.

During April of 1921, the writer assisted in a reconnaissance, undertaken by the plant physiologist of the Imperial Department of Agriculture, of the condition of the chief lime plantations of Montserrat. In this investigation, the ecological relationship between the soil conditions and the growth of lime trees was especially considered. It became evident during the course of the work that a preliminary discussion of the main features of the soils of Montserrat might be of service in future detailed research into the already much-studied problem of the die-back of lime trees, as well as in connexion with general questions of crop growth in Montserrat. The soil work was accordingly extended to include most of the land now under cultivation in Montserrat.

There has been too great a tendency in the past to discuss the potentialities of West Indian soils in terms of their laboratory analyses alone. Little, if any, reference has been made to their geological, topographical and ecological relationship in the field. In the following article, the geology and the chief physical properties of the main soil types of Montserrat are first described. In Part II, the possible bearing of the chief physical properties and field characters of the soils of lime plantations on the problem of cause of die-back of lime trees is considered in some detail. This part of the article is intended to form a basis for future considerations of the physiological aspects of die-back. For the guidance of workers in soil problems in the West Indies, an account of the methods used in this investigation is given in Part III of this paper.

The writer wishes to acknowledge his indebtedness to W. Robson, Esq., Curator of the Montserrat Botanic Station, for help in collecting certain data connected with the Agricultural conditions in Montserrat, and to A. W. Gallway, Esq., Assistant Curator, for his kindness in obtaining many of the soil samples examined.

PART I. THE NATURAL HISTORY AND CHIEF PHYSICAL PROPERTIES OF THE SOILS OF MONTSERRAT.

(A). THE GEOLOGY AND TYPOGRAPHY OF MONTSERRAT.

Monsterrat belongs to a continuous chain of islands that constitutes the volcanic or inner zone of the Antilles [22]*. This zone extends from Saba in the north to Grenada in the south. The islands included in it are of geologically recent origin, although the majority of them possess a foundation of older volcanic rocks of probable Miocene age. [15].

The rocks of which Montserrat is composed consist almost entirely of fragmental material derived from igneous rocks of subalkaline type, chiefly hypersthene-andesite or trachyte [21, 27] This fragmental material has been ejected from sev-

*The figures in small type indicate the numbers of the references to literature cited in the appendix.

eral centres, so that several distinct volcanic cones are recognizable in the island. The chief of these comprise the South Soufrière Hill, (2,500 feet); the Soufrière Hills, (3,000 feet); the Centre Hills, (2,500 feet); St. George's Hill, (1,200 feet); and Silver Hill, (1,300 feet).†

No lava flows appear to exist in the island. Coral rock, forming recent fringing reefs, occurs in places round the coast.

Since its ejection, the fragmental volcanic material has been largely consolidated into agglomerates, breccias and tuffs, which are clearly to be seen in numerous sea-cliff sections. Where these rocks are exposed at the surface of the land, as they are especially in the northern half of the island, they are locally known as 'Shoal' rock.

Extensive erosion has gone on in the highlands of Montserrat. One result of this has been the formation of several well-marked talus slopes, composed of loose material which spreads out in fan-shapped masses from deep cirques situated near the summits of certain of the mountains, and reaches down to the coast. The most conspicuous of these talus slopes occur in the south of the island, having their origin in the Soufrière Hills. Especially noteworthy are the talus slope that abuts on the south-west coast between Plymouth and O'Gara's, and the slope which terminates in the gently inclined ground on the east (windward) side of the island between Trant's and Tar River. A third series of smaller talus slopes of some importance extends from the St. George's Hill range westward to the coast north of Plymouth.

Surface erosion has carved out of the loose material of which the talus slopes are composed, numerous narrow ravines which possess almost vertical walls. These ravines are locally known as 'ghauts' or 'guts,' and are frequently of great depth. They are usually dry except during periods of excessive rainfall. In those parts of the island where talus slopes are absent or poorly developed, river action has eroded the hillsides into deep valleys. These are especially prevalent in the hill mass known as the Centre Hills, and in the central and northern parts of the island generally. They are quite distinct from the ghauts of the talus lands.

Possibly the almost entire absence of talus slopes in the northern half of Montserrat, and the occurrence, in this region, of well developed valleys, indicate the greater age of the northern part of the island; for long-continued erosion would have the effect of removing loose debris accumulated as a result of water action of former times.

The cultivated lands of Montserrat occur chiefly on the lower parts of the hill spurs and talus slopes. They are seldom found at elevations of more than 1,500 feet. At altitudes greater than this, natural vegetation, belonging chiefly to the indigenous forest association, covers the land surface.

---

†These names are taken from the Admiralty map of Montserrat, first published in 1869.

(B) The Main Soil Types of Montserrat.

The soils of Montserrat may be subdivided into two main types in accordance with their geological origin. These types may be designated—

(1) Talus soils.
(2) Shoal soils.

(1) TALUS SOILS.

Talus soils, as the name implies, are distributed over those areas where talus slopes occur. They are typical soils of transportation. The chief feature exhibited by them is their marked porosity, for they pass downwards into considerable thicknesses of loose subsoil, so that their natural under-drainage is exceptionally free. The majority of the best cotton growing estates in Montserrat are situated on talus lands, as, for example, Grove, Dagenham, and Trant's.

The cultivated talus soils of Montserrat occur chiefly at low elevations, where the rainfall is comparatively small, ranging between 40 and 60 inches per annum. Their more important physical characters may be learned by an inspection of Table I, in which the results of laboratory examination, made by the writer, of representative samples of talus soils are displayed. The data published by Watts and Tempany, who conducted a soil survey of Montserrat in 1905[27], convey further information as to the physical constitution of the talus soils, as well as to certain of their chemical properties.

The facts may be summarized as follows. The talus soils of Montserrat are light, fawn-coloured, loamy sands, notably deficient in colloidal matter, and, for this reason, not very retentive of water. Their permeability is relatively very high. The soils are usually easy to till. In some localities, however, the occurrence of a high proportion of stones and small boulders interferes with tillage. On the other hand, these larger fragments lying on the surface of the land, serve in some measure to minimise loss of soil moisture by evaporation. The soils at O'Gara's, and also at certain estates situated on the large windward talus slope above Trant's (including Farm, Bethel, Tuit's and White's) are especially characterized by this feature.

Generally speaking, the lands in which loose boulders and stones preponderate, are situated on the higher or more inland parts of the talus slopes. This is a natural result of the action of mountain torrents, which are the agent that has given rise to these slopes.

The addition of bulky organic manures is the only practical means whereby the water-retaining capacity of the sandy talus soils can be increased. Soil moisture may be conserved in the drier months of the year by maintaining a loose soil mulch (see[20], [28]). This practice should receive more attention in Montserrat.

Chemically, the talus soils are highly fertile [27]. The soil reaction is distinctly alkaline, in spite of the fact that the soils contain only small amounts of carbonate. In the light of modern knowledge as to the significance of soil reaction[11], there would appear, however, to be no necessity for liming.

(2) SHOAL SOIL.

Soils of the second main type cover those areas of Montserrat where talus slopes are absent. They constitute the major part of the uncultivated land of the island, as well as land that is unsuited to the growing of the best cotton. Shoal soils are typical sedentary soils, for they have been derived from consolidated fragmental rocks which they usually directly overlie. For this latter reason, natural under-drainage is at a minimum; a fact which distinguishes the soils markedly from those of the talus slopes.

Shoal soils are typically developed in the northern half of Montserrat; they also occur in the extreme south-eastern part of the island in the South Soufrière district.

Consequent on differences in the amount of rainfall (which are the result of varying altitude), in the degree of land slope, and in the presence or absence of a natural covering of vegetation, three distinct sub-types of shoal soils may be defined. For convenience of description, these may be designated :—

(a) Humid upland Soils.
(b) Hilly land Soils.
(c) Valley Soils.

The sub-types named in this list merge imperceptibly one into the other. The factors that have been responsible for their differentiation are mainly climatic and topographical in nature, as is indicated by the names chosen for the sub-types.

(a) *Humid upland Soils.* Soils of this sub-type occur in Montserrat at elevations of 1,000 feet and over. The annual rainfall in these regions varies between 60 and 100 or more inches. The greater part of the Montserrat uplands lying above the 1,000 feet contour is still clothed with virgin forest of floristic composition, very similar to that comprising the dense forests which almost entirely cover the humid mountainous islands of the Lesser Antilles (Dominica, Martinique, St. Lucia, etc.), and which occupy the more elevated regions of the majority of the other islands of the group.

The soil conditions in the uplands of Dominica, where the annual rainfall varies between 150 to 300 inches, have been discussed by the writer in a recent paper[2]. The main features of the upland forest soils of Dominica are exhibited in modified form by the upland soils of Montserrat.

The chief physical characteristics of the Montserrat upland soils are set out in Table II. Sample 5 was taken at an altitude of about 1,300 feet, from forest land where cacao and lime trees have been planted. It is typical of the unreclaimed forest soils of Montserrat. The soil is markedly acid in reaction (pH 6·7). It is not so acidic, however, as the Dominican upland soils, whose reactions vary between pH 4·4 and 5·1 ([1], p. 101). This fact may be interpreted as indicating that leaching has not gone on so extensively in the Montserrat uplands as it has in those of Dominica, and is doubtless accounted for by the lower rainfall of the former region.

As may be inferred, the Montserrat upland soils exhibit incipient lateritization ([11], p. 47 ; [12], p. 97). The soils when dry are of a reddish or yellowish colour, showing the presence of an excess of iron oxide. They are distinctly colloidal in type, and for this reason, possess high water-holding capacities and low permeabilities. Their subsoils are clayey, and of varying depth.

At Farrell's and Harris's on the broad divide that separates the Centre Hills from the Soufrière Hills, at an elevation of some 1,000 to 1,100 feet, the upland soils have been reclaimed for cultivation. They have, for a considerable period of time, been given over to the cultivation of sugar-cane. These areas are unsuited to the growth of the cotton crop, for, besides possessing a heavy type of soil, the situations are exposed to wind, and the rainfall is excessively high.

At Tar River estate, the upland soil is a yellowish brown clay-loam of considerable depth. It has been reclaimed by the recent deforestation of certain of the western spurs and valleys of the Soufrière Hills.

At Roache's occurs the most productive upland soil in Montserrat. It is a deep, brown-coloured loam, rich in humus. It supports good crops of sugar-cane.

(b) *Hilly land Soils.* In marked contrast to the talus soils and to the upland forest soils, there exist in Montserrat considerable areas of land of a generally infertile nature. Such areas are typically represented in the Silver Hill region at the northern extremity of the island and occur below the 1,000 feet contour. Here the land surface is broken up into steep hills and deep valleys. The rainfall is comparatively small, being below 40 inches per annum in some localities.

The hillslopes are exposed to wind, and in the drier months of the year are parched and bare. The soil is shallow and is underlain by consolidated volcanic ejectamenta or 'shoal.' In consequence, drainage is entirely superficial, so that in rainy weather, water quickly runs away.

The texture of these hill-slope soils is mainly sandy. Sample No. 3, Table III (Cavalla Hill) is typical of them. This soil is of low retentivity, and most of the colloidal matter has been washed out of it. It can support crops only in the wetter months of the year, and is best suited to the growth of ground provisions, whose vegetative periods are of short duration. The soil is too shallow and too subjected to water-logging in rainy weather to yield satisfactory crops of cotton.

A certain number of successful cotton estates are situated, however, on the hilly shoal lands in the northern part of Montserrat. These estates occur in localities where the topography of the ground offers some shelter from wind, and where the soil is of somewhat above the average depth. Many of the steeper hillsides in the extreme north and north-eastern regions of the island are cultivated by peasants. The soil occurs in pockets between exposed rocks, but nevertheless it can be made to produce fair crops of cotton, in spite of the difficult nature of the ground, and the general dry conditions that prevail.

Table III presents data obtained by an examination of soil samples taken from a number of hilly land estates lying between Silver Hill and the Centre Hills. An inspection of these data indicates that the soils vary in type between sandy loams and clay loams. They are pale reddish-brown in colour when dry, and slightly acid, neutral or distinctly alkaline in reacion. A red clay subsoil underlies the soils. This passes rapidly in most places into the shoal rock at no great depth.

The lower and less steep of the hills in the northern part of Montserrat have not been subjected to denundation to the same extent as have those of the more elevated regions of the island such as are unprotected by forest growth. This is especially noticeable in the hills that fall in gentle undulations to the seacoast in the north-west part of the island. Here the comminuted products of rock weathering have remained *in situ*, or have collected in the hollow places. The soil produced from this debris is markedly clayey, and is frequently of considerable depth. Such clay soil is typically developed at Olveston (see [27], p. 280) where its untractable nature caused the abandonment in 1910 of the Experiment Station that formerly existed there.* The clay soils of the foot hills are unsuited to the growth of the majority of crops, excepting certain grouud provisions.

A characteristic natural plant association occurs on the slopes of the low hills of the north-west coastal region. The dominant species of this association are thorny xerophytic shrubs, such as various 'cossies' (*Acacia farnesiana*, etc.); Sages (*Lantana* spp., and *Cordia cylindristachya*,) and the common croton (*Croton flavens.*) This plant association is represented in many West Indian islands, and invariably occurs on shallow, badly-drained pockety soil that covers dry, wind-swept hills near the seacoast. It has been named by Egger the *Crotoneta* association. [6]

(c) *Valley Soils.* In the valleys of the northern part of Montserrat, considerable thicknessess of weathered rock debris have collected, and have given rise to a third type of shoal soil. By reason of the shelter from wind afforded by these valleys, and the general humid conditions of air and soil, occasioned by the permanent presence of streams in them, the northern valley soils are of considerable fertility. They support a prolific natural vegetation of an arboraceous type, especially in their lower reaches. In places, they have been planted with lime trees, as for example, at Old Road, Ile's Bay and Elberton. Many fruit orchards have been established in them. The uniformity of these valley soils is broken by the presence of boulders, except in those regions near the coast where the valley floors widen into small alluvial flats. The soils are sandy loams

*Report of the Montserrat Botanic Station, 1909--10, p. 20.

or clay loams, similar in physical properties to certain of the hilly-land soils last described. They differ from these, however, in that their under drainage is good, and in that they are not subjected to drought. Sample 3, Table IV, is typical of the soils of the smaller of the northern valley bottoms.

In the central part of Montserrat, a wide and large valley separates St. George's Hill from the Centre Hills. The river

which it contains (Belham River) has its origin in the Soufrière Hills, whence it flows in a north-westerly direction to the sea at Old Road Bay. The gently sloping sides of this valley include large areas of productive land as, for example, the lower parts of Lee's-Week's and Waterworks Estates. The chief crops grown are sugar-cane and cotton.

The soil in this region has been derived in part from talus slope material to the south, and in part from the weathered shoal rock to the north. It is therefore a typical transition soil. In physical character, it is a deep silty loam grading into a sandy loam when traced northwards. Unfortunately, no samples of these transition valley soils were examined in detail by the writer, but a study of the data presented by Watts and Tempany ([27], pp. 267 and 278) will indicate their general features and relationships.

TABLE I. : (1) *Talus Soils.*

Soil Number.	Name of Locality.	Height above sea-level (feet).	Rain fall (inches per annum).	Physical soil type	Colloidal matter (per cent.).	Max. water-holding capacity (per cent.).	Permeability to water (Pw X 100).	Reaction pH value.
11.	Trant's.	20	43	Medium sandy.	10·6	29·8	15·4	7·3
2.	Grove (Upper)	250	58	Loamy sand.	14·4	39·2	7·8	7·2
1.	Grove (Bot. Sta.)	150	60	Loamy sand.	15·3	44·5	15·0	7·3
16.	O'Gara's (Lower)	50	43	Loamy sand.	16·1	50·6	20·7	7·3

The following soils belonging to this type were examined by Watts and Tempany [27] : Trant's, Grove, Gage's, Bethel and White's.

TABLE II : (2) *Shoal Soils.*

Sub-type (a), Humid Upland Soils.

5.	Centre Hills	1,300	100	Clay soil.	40·4	62·4	1·1	6·7
17.	Roache's (Upper)	1,400	90	Sandy loam.	27·2	55·3	8·9	7·2
20.	Tar River (Upper)	1,000	80	Clay loam	32·7	50·4	7 0	6 9
12.	Farrell's	1,100	80	Clay loam.	30·6	50·2	5·6	6 7
13.	Harris's	1,000	60	Sandy loam.	26·3	48·7	4·2	7·0

Examined by the Watts and Tempany [27] : Tar River, Farrell's, Harris's.

TABLE III : (2) *Shoal Soils (Cont'd.).*

Sub-type (b), Hilly Land Soils.

8	Cavalla Hill	500	60	Sandy loam.	29·0	42 6	3 2	6 9
10	Blakes	600	55	Sandy loam.	29 3	40·2	6·7	6·8
19	Rendez-vous	200	40	Sandy loam.	28·4	44·1	3·9	7·1
9	Gerald's	400	45	Sandy loam.	27·6	44·3	2 9	6 9
14	Barzey	860	53	Sandy loam	26·3	51·1	7·0	6·7
6	Braid's	300	50	Clay loam	31·4	53·6	5.0	7·6
7	Sweeney's	500	50	Clay loam.	39 8	63·2	5·4	7·4
4	Olveston (foot hills)	300	60	Clay loam.	37·4	60·1	4·4	6 7

Examined by Watts and Tempany [27] : Olveston.

TABLE IV : (2) *Shoal Soils (Concl'd.).*

Sub type (c), Valley Soils.

3.	Olveston Valley,	20	55	Clay loam.	33·1	51·9	6·4	7·1

Examined by Watts and Tempany [27] : Ile's Bay, Lee's, Weeks's.

(C) THE CLIMATIC CONDITIONS IN MONTSERRAT.

It would be convenient for purposes of reference to summarize in this place the data obtained by meteorological observations systematically carried out at several stations in Montserrat, and recorded in the annual reports of the Botanic Station.

(1) *Rainfall.* The following table (Table V) contains the names of stations for which rainfall data are available over periods of not less than five years The stations are arranged in the order of magnitude of their average annual rainfall. The approximate altitude and the geographical position of each station are also stated.

TABLE V. Average annual rainfall returns, Montserrat.

Name of Station.	Average annual rainfall (inches)	Number of years (average).	Approx. altitude (feet).	Geographical position.
Riley's ...	78·2	5	1,000	Leeward slope; central divide.
Woodlands ..	65 9	12	900	Leeward coastal belt; north.
Amersham ...	61·0	6	500	Leeward coastal belt; south.
Waterworks	32·4	6	600	Leeward slope, Centre Hills.
Grove ..	60·5	12	150	Leeward coastal belt; centre.
Olveston ...	60·0	12	600	Leeward coastal belt; centre.
Harris's ...	59·5	12	800	Central divide; highest land.
Richmond ...	58·4	12	200	Leeward coastal belt; centre.
Dagenham ...	53 0	12	150	Leeward coastal belt; centre.
Ile's Bay ...	51·4	12	50	Leeward coastal belt; centre.
Kinsale ...	50·5	12	50	Leeward coastal belt; centre.
Blake's ..	47·5	7	600	Windward slope; northern hills.
Elberton ..	46·8	12	50	Leeward coastal belt; centre.
White's ..	43 7	12	600	Windward coastal belt; centre.
O'Gara s ..	43·5	12	50	Leeward coastal belt; south.
Roaches lowlands ..	43·3	7	500	Windward coastal belt; south.
Trant's ...	40·8	12	50	Windward coastal belt; centre.
Bethel ...	39·3	12	200	Windward coastal belt; centre.
Farm ...	33 5	12	150	Windward coastal belt; centre.

Neglecting the upland regions of elevation of 1,000 feet and over, it is seen from the data presented in Table V, that the magnitude of the rainfall in the different parts of Montserrat is not very great, nor is it very widely divergent. The leeward side of the island, on the average, receives more rain than the windward side. This is directly opposite to the rainfall distribution in the more mountainous of the West Indian islands, as for example, Dominica. In Dominica, the leeward coastal belt is much drier than the windward coastal belt. This difference is so marked that it has made a profound impress on the character of the soils of the two regions (see [12], pp. 94-106). No such differentiation of soil types correlated with geographical position can be definitely traced in Montserrat. On the whole, the districts of highest rainfall in Monsterrat appear to lie on the leeward (western) slopes of the Centre Hills and the Soufrière Hills. Within this region, the more elevated districts receive the greater rainfall. The driest parts of the island occur in the extreme north and south-west, and along the windward coastal belt.

Records indicate that the mean annual rainfall of Montserrat during the past thirty years has exhibited a fairly well-marked periodicity. This is clearly shown by the figures in Table VI, which have been abstracted from the data presented at

page 40 of the annual report of the Montserrat Botanic Station for 1919-20. The average annual rainfall for the island, as indicated by the returns of numerous (6 to 22) stations during the past thirty years, is 57 inches. It has fallen below this in fairly regular four-year periods, and has risen above it in alternate periods, of the same duration. The reason for these facts are obscure. Contrary to repeated assertions, it appears that the average annual rainfall of Montserrat has not decreased abnormally during the past thirty years. This conclusion has some significance in connexion with the question of die-back of lime trees*

TABLE VI. Periodicity in the average annual rain fall of Montserrat during the past thirty years.

Years of low rainfall.			Years of high rainfall.		
Year.	Approximate annual average rainfall	Difference from the thirty years mean of 57 ins.	Year.	Approximate annual average rainfall.	Difference from the thirty years mean of 57 ins.
1894	47	-10	1896	93	+36
1900	43	-14	1901	65	+ 8
1904	48	- 9	1906	67	+10
1907	47	-10	1909	66	+ 9
1912	42	-15	1913	56	-
1914	46	-11	1916	68	+11
1918	46	-11	-	-	-

The rainiest months of the year in Montserrat are usually September, October and November. The months December to June are generally comparatively dry, so that there is some indication of alternating wet and dry seasons in the climate of Montserrat. This alternation is not, however, always very clearly marked; the rainfall may be relatively large during any period of the year.

(2) *Prevailing Winds.* Montserrat is windswept for the greater part of the year. During the drier months, the north-east trade wind blows with great persistence, and frequently with violence. The exposure to wind of lime trees growing in open fields is a factor which has been considered of major importance in the relation to the growth

*Annual Report of the Montserrat Botanic Station, 1917-18, p. 13.

of limes in Montserrat†. Attempts to minimize its effect by the planting of wind-breaks have received increasing attention from lime growers in recent years*.

Some idea of the velocity and regularity of the wind in Montserrat may be learned from the observations which have been recorded at the Botanic Station since 1915*. The average wind velocity, measured in miles per hour, is 8·3. It is greatest, in general, during the months of January to August.

(3) *Atmospheric temperature and humidity.* Records of atmospheric temperature at the Grove Botanic Station have been kept since June 1913. The mean maximum temperature for the seven-year period, 1913-19, is 86·6°F, and the mean minimum, 73·4°F.

The mean relative humidity of the atmosphere at the Botanic Station over the five-year period 1915-19 is 70·9 at 9 a.m., and 65·1 at 3 p.m.

Unfortunately, no meteorological records are available for other localities in the island nor are any similar data available for Dominica. One cannot therefore draw exact comparisons between the atmospheric conditions of the two somewhat contrasted regions in which the lime tree is grown.

PART II. THE RELATIONSHIP BETWEEN CERTAIN SOIL FACTORS AND DIE-BACK OF LIME TREES.

(A) The Problem of Dieback of Lime Trees in Montserrat.

The cultivation of the lime tree in Montserrat has been attended from the date of its inauguration in 1852 with many difficulties. Especially since the disastrous hurricane of 1899, has the condition of the lime orchards been steadily deteriorating. The records published in the annual reports of the Montserrat Botanic Station subsequent to 1906 contain repeated reference to this unsatisfactory state of the lime industry.

The decline of the lime trees has taken the form of a gradual cessation of growth, accompanied by a dying back of branches and frequently also, a yellowing or mottling of foliage. An almost invariable symptom of die-back, concomitant with those above-mentioned is the marked prevalence of scale insects on the branches and leaves of affected trees. Occasionally the roots show damage due to attacks of soil grubs, and, finally, infestation of twigs and roots by certain fungi has been noted

The constant association of scale insects with the die-back condition led to the original belief that the two were causally connected. Hence the early attempts to combat die-back of lime trees consisted of various cultural treatments of the soil, and of spraying trials with different insecticides, the immediate object of which was the suppression of scale. Efforts to encourage the spread of entomogenous fungi and of certain predaceous enemies

† Ibid, 1915-16, p.11.
* Ibid, 1918-19, p. 17; 1919-20, p. 27.
* Ibid. 1915 to 1919.

of scale insects by sheltering the lime trees with screens of shrubs or covers of creeping plants, were also made at various times. The result of these experiments are fully described in the annual reports of the Montserrat Botanic Station published during the past twelve years. On the whole, the experiments were not very successful.

During recent years there has been an increasing tendency to consider scale insects and fungi as facultative rather than causative parasites of lime trees in Montserrat, and to lay most stress on the direct effects of an unfavourable environment, as the major factor responsible for die-back* The accumulated evidence, as far as it is susceptible of interpretation, points especially to unsatisfactory water relations between the lime trees and their environment as the most likely reason for the persistent failure of the trees, not only in the older plantations, but also in those that have been but recently laid down.

In the absence of records of actual numerical measurements of the factors that affect the water relations between the lime plant and its environment, no definite conclusions, however, can be drawn from the scanty data available.

It was with a view to obtaining further insight into the ecological conditions under which lime trees are growing in Montserrat that the plant physiologist of the Imperial Department (T.G. Mason) and the writer visited the island in April 1921. During this reconnaissance, the writer's especial concern was with the soil conditions of the lime plantations, considered in their broadest aspect. The results of this investigation are set out in the following paragraphs. The physiological phases of the die back problem will receive detailed consideration in a seperate paper. by Mason. It is hoped that these contributions to our knowledge of the causes of die-back of lime trees, will lead to greater definition of the problem of its elimination, and to the formulation of more successful methods of lime orchard cultivation. It is not to be expected that conclusive evidence can be collected by making a limited number of observations during a short visit covering only a very small fraction of the total vegetative period of the plant species under consideration. Nevertheless, a preliminary investigation of an ecological problem frequently suggests the form which future detailed work should take, and fixes the attention of officers concerned in the routine study of a particular crop on the salient facts about which further information is desired.

(B) Soil Conditions in Relation to Die-back.

The preliminary soil investigation now to be described consisted in the collection and examination of representative samples of the soil of certain lime plantations, with a view to detecting variations that might in part be correlated with the incidence of die-back. Samples were taken of soil in which were rooted (A) lime trees exhibiting die-back, (B) healthy lime trees

*Annual Report of the Montserrat Botanic Station, 1915-16, Mycologist's Report, pp. 9-12.

Each sample was composed of mixed surface soil obtained from the root region of ten trees of the same age and general condition. Soil samples A and B were produced from each of three districts in Montserrat at present in lime cultivation. The names of these districts are (1) Grove, (2) Olveston, (3) O'Gara's. They are typical of the lime-growing areas belonging to the Montserrat Company.

For purposes of comparison, soil samples 4 A and 4 B were obtained in Dominica. The first of these was taken from Saltoun Estate, in the rainy upland region of the interior of the island. The second was taken from the mulched plot of the Roseau Lime Experiment Station.

Finally, soil samples 5 A and 5 B were obtained in Antigua at Dimsdale Estate situated in the south-east of the transition region of the volcanic area, (see [27]; soil number 43, pp. 96-97). Dimsdale is the only locality in Antigua where limes are grown as an orchard crop[25].

The accompanying table (Table VII) presents the data obtained in an examination of the soil samples enumerated.

Table VII.

RESULTS OF AN EXAMINATION OF SOIL SAMPLES OBTAINED IN CONNEXION WITH A PRELIMINARY INVESTIGATION INTO DIE-BACK OF LIMES.

Soil number, and state of trees.	Name of locality.	Rainfall (inches per annum).	Physical soil type.	Maximum water-holding capacity.	Permeability to water (Pw × 100).	Reaction Ph value.	Organic matter (per cent.).	Soluble humus (per cent.).
	Montserrat.							
1 A*	Grove, (Belle field)	58	Loamy sand	39·2	7·8	7·2	1·84	0·68
1 B†	Grove, (Bot. Sta.)	60	Loamy sand	44·5	15·0	7·3	2·15	0·70
2 A	Olveston, hilly land	60	Clay loam	60·1	4·4	6·7	5·15	1·05
2 B	Olveston, valley	55	Clay loam	51·9	6.4	7·1	4·.7	0·73
3 A	O'Gara's, coastal land	43	Loamy sand	50·6	.0·7	7·3	2·41	0·56
3 B	O'Gara's, hill.	45	Sandy loam, very stony	44·4	7·4	7·5	3·03	0·89
	Dominica.							
4 A	Saltoun, 9-acre plot	200	Humus silty soil	100·0	9·5	4·7	16·87	6·40
4 B	Mulched plot, lime expt. sta.	80	Sandy loam	44·3	4·1	6·8	2·96	1·17
	Antigua.							
5 A	Dimsdale, Nora field	40	Fine silty soil	59·5	0·5	7·5	2·34	0·51
5 B	Dimsdale, valley.	40	Fine silty soil	49·3	1·9	7·5	2·36	0·50

*Soil samples A represent soils supporting trees that exhibit die-back.
†Samples B represent those supporting normal trees.

NOTES ON THE ENVIRONMENTAL CONDITIONS DURING APRIL 1921 AT THE LOCALITIES AT WHICH SOIL SAMPLES WERE TAKEN.

MONTSERRAT.

1 A. *Grove Estate*: Lime trees exhibiting die-back.

The Grove Estate soil sample was taken from the lime plantation known as Belle field. It was here that certain cultural and spraying experiments, designed with a view to suppressing attacks of scale insects, were inaugurated in 1915* The soil is of the talus slope type, free from large stones, and in good tilth. It was over-run with creeping weeds, cheifly *Commelina nudiflora* and *Momordica charantia.* The situation is exposed to winds, and the existing artificial wind-belts appear to be inadequate.

1 B. *Grove Botanic Station*:-Lime trees free from die back.

The soil of the small lime plot at the Botanic Station is of similar type to the last. It is very uniform in texture, deep and uncompacted. A heavy mulch of cane grass, cut from a neighbouring plot, covered the soil surface. In consequence of this, and partly also because of the sheltered position of the lime plot, the soil at the time of sampling was moist to the touch. At the lower end of the plot, the soil is deepest and moistest. The whole lime plot was free from weeds. Well-grown specimens of the leguminous shrub, *Gliricidia maculata*, occurred between the lime trees. These had been planted in pursuance of a practice first advocated in 1914. †

2 A. *Olveston*:—Lime trees exhibiting die-back.

This locality is situated on the gently sloping side of an exposed low hill near the seacoast. The soil is of the hilly-land shoal type, and supports the *Crotoneta* plant association, described in another place. It is very shallow and rocky. The lime trees have been planted chiefly in pockets of soil. At the time of sampling, the soil was very dry and compact.

2 B. *Olveston valley*:—Lime trees free from die-back.

The soil in this small valley near the sea is typical of the valley soils of the northern part of Montserrat. It is rocky but deep, especially in the pockets between boulders. The situation is sheltered, and the soil, at the time of sampling, was moist to the touch. The weeds growing between the lime trees were tall and vigorous They consisted chiefly of species belonging to the Gramineae, Leguminoseae, Malvaceae and Acanthaceae. *Commelina nudiflora* and a species of broad-fronded fern were abundant. The plant-assemblage was similar to that occurring in many humid regions of the West Indies, and resembles the flora of the bases of gullies in Barbados.

---

* Annual Reports of the Montserrat Botanic Station, 1915-16 to 1918-19 inclusive. Also *West Indian Bulletin*, XI, 1911, p. 39.

† Ibid. 1914-15, p.8.

3 A. *O'Gara's, coastal region*:—Lime trees exhibiting die-back.

This locality is situated on low ground near the extremity of a steep talus slope. The soil, however, is not typical of the talus soils of other districts. It is somewhat shallow and stony, with pockets between rocks. It was dry and compacted, and its weed flora was withered. Under-drainage appears not to be good, for the presence of nut grass (*Cyperus rotundus*) and *Commelina nudiflora*, growing amongst the xerophytic short-lived annuals that make up the natural plant association indicates that the land is subjected to perodic water-logging.

3 B. *O'Gara's, hillslope*:—Lime trees free from die-back.

The steep talus slope above O'Gara's is dissected longitudinally by deep ghauts, bordered by steep round-backed ridges. In the ghauts a certain amount of shelter from winds is experienced, but the slopes of the divides are exposed and dry. The lime plot examined occurs in one of these sheltered ghauts, at an elevation of some 250 feet. The soil is a brown deep loam, and is characterized by the presence over its surface of a very well-marked layer of volcanic cinders and small stones. These make up over 50 per cent of the bulk of the top soil, and their size varies between 3·0 and 0·5 cm. They form a loose stone-mulch on the soil, and, when removed, expose a plexus of lime rootlets which ramify through the moist soil. No distinctive natural plant association occurs here, but sporadic clumps of a tall grass (*Paspalum* sp.), and a yellow-flowered cactus (*Opuntia* sp.) are conspicuous amongst the lime trees.

DOMINICA.

4 A. *Saltoun, 9-acre plot*:—Lime trees exhibiting die-back.

The general conditions that prevail in the humid upland regions of Dominica, where Saltoun is located, have been briefly described in the writer's paper on the soils of that island, ([12], pp. 101, 104, 116.). The soil at Saltoun is shallow, and overlies sheet rock. The subsoil is a yellow clay. The drainage is mainly superficial, the land sloping in the direction of a natural watercourse. As a result of very high rainfall, the soil has been subjected to leaching and washing. It is markedly acidic in reaction, and it is almost continuously water-logged. The area is overrun with rank weeds, of which the panache grass (*Andropogon* sp.) supposed to indicate poor soil, is especially noticeable. The soil itself contains a high percentage of organic matter, and, for this reason, possesses a high water-holding capacity.

4 B. *Roseau Lime Experiment Station*:—Lime trees completely free from die-back.

The conditions obtaining in the sheltered valley on the southern slope of Morne Bruce where the lime plots are situated, have been described at pages 102 and 112 of the article on the Soils of Dominica already cited. The mulched plot (13 e), which supports a vigorous and healthy crop of lime trees, is well drained, and is composed of soil in good tilth and of considerable depth. It is adequately sheltered from winds by the proximity

of lime trees of neighbouring plots, and by a dense artificial wind-belt that lines the nearest hill crest.

ANTIGUA.

5 A. *Dimsdale, Nora field* :—Lime trees exhibiting die-back.

The field is situated on gently sloping ground overlooking Falmouth Harbour, and is somewhat exposed to wind. The soil is very uniformly fine-grained, containing about 50 per cent. of fine silt, and a negligible amount of clay. In consequence it packs tightly when wetted, a result which is clearly indicated by the remarkably low permeability constant which the soil possesses. At the time of sampling (April 21, 1921), the ground was hard, dry, and much compacted. The soil is of considerable depth, but is somewhat lacking in organic matter. It is kept clean weeded, but no regular loose soil-mulch was observed.

5 B. *Dimsdale, sheltered low ground* :—Lime trees less affected by die-back.

The locality from which this soil sample was obtained, lie about ½-mile to the south of that from which the last sample was taken. A small watercourse runs through the area. The soil is coaser in texture than the last, but at the time of sampling, it was compacted and somewhat dry. The cultural treatment given to the soil is similar to that described in the last paragraph.

DISCUSSION OF THE DATA.

An examination of the figures in Table VII indicates no regular and marked differences in the values obtained for the several physical soil constants that have been determined on samples constituting each pair of representative soils. With the exception of 4 A and 4 B, the soils supporting healthy and die-back trees are texturally similar. Their water-holding capacities, and hence their content of collodial matter, are not markedly different. There permeability constants, however, vary somewhat, but never in the same direction.

The condition of the soils, as indicated by the reaction, is, in all cases except 4 A, satisfactory. None of the soils, with the exception stated, possess soil solutions in which the concentration of hydrogen-ion is sufficiently high to cause one to suspect the presence of certain inhibiting factors which might be correlated with unsatisfactory plant growth. All the soils contain medium to large quantities of organic matter, and of soluble humus.

The humus content of soils supporting citrus trees has been shown to be a controlling factor in certain districts of California There Briggs and his collaborators of the United States Bureau of Plant Industry found a mottling of the leaves of orange trees to be definitely correlated with a low content of soluble humus in the soil, and that mottling decreased as humus content increased. This discovery led to the adoption of the mulched-basin system of citrus culture, an innovation which has been followed by

a marked improvement in the condition and productivity of the citrus groves. ([4], [5]). The relation between humus content and and yield of orange trees has been further studied by Jensen, ([10]), who concluded that the active component of vegetable mulch appears to be the degradation products of freshly decomposing organic substances, rather than the soluble humus formed therefrom. There seems to be no specific advantage in using a leguminous plant rather than a non-leguminous plant as mulching material in citrus groves.

These conclusions are very suggestive, in view of the recent work in England of Bottomley ([2], [3]), who maintains that decomposing vegetable matter gives rise in the soil to small quantities of certain complex compounds (auximones) which play a rôle in plant nutrition very similar to that of vitamines in animal metabolism.*

That the organic carbonaceous component of the soil is particularly important in the growth of citrus trees in the West Indies, is demonstrated by the results of manurial experiments now being conducted by Jones in Dominica†

Here it is found that a thick layer of vegetable mulch encourages the formation by the lime trees of numerous surface roots, which is accompanied by an increase in the productivity of the trees. The result may perhaps partly be explained in terms of the physical benefits which organic matter confers on the soil, especially those that are correlated with water supply. Possibility also, it may in part be due to the specific nutritional properties which humus appears to possess.

Returning to a consideration of the results of the soil investigation described in this article, it would appear from the figures contained in Table VII, that the soluble humus in the soil is not the main factor responsible for the die-back condition in the lime-growing districts of Montserrat, Dominica and Antigua. Briggs and his collaborators found that healthy citrus trees flourished on substrata in which the content of soluble humus was in excess of 0·2 per cent. [1]. This lower limit is not reached in any of the West Indian lime orchard soils examined by the writer (Table VII).

The total amount of organic matter in the West Indian citrus soils, however, is very variable, and with the exception of the districts where soil samples 1 B, 4 A, and 4 B were obtained, the organic matter does not occur specifically as a definite surface mulch that might exercise control over the water relations between the lime trees and their sub-aerial environment. The special question of the value of heavy mulch dressings in citrus orchards in the West Indies is well worthy of continued intensive study.

There are numerous soil factors other than those so far considered in connexion with the die-back of lime trees in the West Indies, that might have bearing on the causes of this condition. For example, Essig maintains that a certain

---

* See *Agric. News*, XIX, 480, p. 295; Sept. 18, 1920.

† Annual Reports of the Dominica Botanic Station, 1912 to 1920.

die-back condition of citrus trees studied by him is produced by an irregular or improper food-supply. An excess of ammonium compounds in the soil is given as one unfavourable soil condition which may cause die-back. An irregular water-supply is also stated by Essig to lead to die-back in certain types of Californian soils that receive insufficient amounts of nitrogenous fertilizer

Lipman[18] claims, a poor nitrifying power in a soil which exhibits normal ammonifying power, may also cause die-back of citrus trees. In such a soil, the trees do not obtain a sufficient supply of nitrates, and are forced to assimilate ammonium compounds. Furthermore, when a soil's power to fix ammonium compounds is very feeble, owing to the presence of a large excess of base, a poor nitrifying power, and a strong ammonifying power may lead to nitrogen starvation of citrus trees rooted in that soil. This conclusion is in some accord with the writer's own observations on the relationship between reaction and fertility in certain lime plantations of Dominica, where it was found that those soils which possessed a limited, yet sufficient, supply of easily available base, supported, in general, the most productive crops of lime trees (12, p. 116).

Finally, Kellerman and Wright[17] noted that applications of excessive amounts of nitrogenous fertilizers frequently lead to deterioration in citrus groves. An excess of calcium carbonate in the soil was found to hasten this deterioration, in that it induced a too rapid production of soil nitrates.

In British Guiana, it has been shown by Harrison, Stockdale and Ward[13] that, during the dry season, there is an almost complete absence of ammonium compounds and a relatively large excess of nitrates in the soil. With the saturation of the soil by rains, however, the condition is reversed, and much of the nitrate nitrogen is reconverted into ammoniacal nitrogen. Possibly this sequence of events obtains in the soils of other West Indian regions where dry and wet seasons alternate.

The relationship between die-back of lime trees and the transformation of nitrogen compounds in the soil has not yet been investigated in detail in West Indian lime plantations.

It is evident, however, from the foregoing discussion that the question of nitrogen supply is intimately bound up with that of water-supply, for variations in the water-supplying power of the soil of citrus groves is apparently accompanied by corresponding variations in the rate at which suitable nitrogenous compounds are rendered available to the citrus trees. Hence it is apparent that a detailed study of the water-supply of lime plantation soils should form a necessary prerequisite to a detailed study of the more specific questions connected with the nutrition of citrus trees.

It has already been stated that the data set out in Table VII, *considered without reference to the general condition of the sub-aerial and the atmospheric environment* in those lime-growing districts examined in the preliminary reconnaissance described in this article, do not indicate the operation of any distinctive factors that might be correlated with die-back.

A consideration of the more general aspects of the environment of healthy lime trees exhibiting die back, points, however, to certain features that might be of major importance in their relation to the die-back condition. Thus it may be noted that in those districts where lime trees are making satisfactory progress, the situations are sheltered from wind, and, in general, are such that extreme variations in atmospheric humidity and amount of soil moisture are at a minimum. In each case, the geological and topographical relationship of the soils supporting healthy lime trees, tends to bring about an equalization in the rates at which the soil can supply water to the tree roots during extreme periods of drought and of rainy weather. Whereas lime trees growing on shallow, badly drained soils usually exhibit die-back, those that are rooted in deep well-drained and surface-mulched soil are less affected by the die-back condition.

Further detailed investigation, conceived with a view to giving actual numerical expression to the variations that occur throughout the year in the atmospheric humidity and in the water-supplying power of the soil of lime plantations is needed before the full importance of the water relations between the lime tree and its environment can be finally established. Such an investigation is practicably possible, and methods are available whereby the necessary measurements can be made. That variations in the water relation of the lime tree have had their effect in impressing certain morphological features on the lime itself, will be shown in the paper to be presented by Mr. T. G. Mason.

PART III.

METHODS USED IN THE SOIL INVESTIGATION.

1. *Preparation of the soil sample.*

The samples were taken with a trowel to a depth of 1 foot. No subsoil samples were obtained. The samples were sent to the laboratory and air-dried. They were then rubbed in a mortar with a wooden pestle and sifted through a 2 mm. sieve. The proportion of gravel and stones was noted. The sifted soils were used in all the experiments described below, excepting No. 6.

2. *Colloidal matter* (approximate).

This was estimated by measuring the linear shrinkage of bricks of dimensions $3 \times 1 \times 1$ inches, exactly as described by Auchinleck[1] and by Tompany[2,4] The percentage colloidal matter was calculated from the percentage linear shrinkage by multiplying by Tempany's factor, 4·25.

3. *Maximum water-holding capacity.*

The maximum water-holding capacity of a soil is defined as the quantity of water which the soil contains when completely saturated but freely drained. It may be expressed as volume per cent. or weight per cent. It is usually estimated by the method of Hilgard (14, p. 209). This consists in measuring the quantity of water (volume or weight) which a known amount of the dried soil, contained in a perforated cylindrical brass box * of 6 cm. diameter, and 1 cm. height, soaks up when the box plus soil is placed in a shallow dish of water, and allowed to remain there for an hour. The maximum water-holding capacities of the soils examined by the writer were determined in this way. The magnitude of the result obtained in any one case depends on the mode of packing the soil particles, and on the absorptive capacity for water of the colloidal matter present.

A comparison of the figures in columns 6 and 7 of Tables I-IV shows the general relationship that exists between the amounts of colloidal matter present in the Montserrat soils and their maximum water holding capacity. Much of

the colloidally absorbed water of soils is available for plant growth. To bring about an increase in the water-holding capacity of a soil, one must add colloidal matter to it. The kind of colloidal matter usually applied in practice is humus. Pen manure and decayed plant residues are composed mainly of humus. The necessity of adding such bulky organic manures to the sandy loam soils of Montserrat as a means of increasing their water-supplying power, has already been urged.

4. *Permeability to water.*

The permeability of a soil to water is defined as the quantity of water which passes per second through a layer of the soil 1 sq. cm. in cross-sectional area and 1 cm. thick, under a head of 1 cm. pressure[9]. It is usually estimated by a percolation experiment.

The values representing the permeabilities of the Montserrat soils examined by the writer were determined as follows :—

Tinned iron tubes of dimensions 16 inches by 1½ inches sectional area were procured. These had a side tube of lead soldered into them at a point 13 inches from one end. In an experiment, the end of a tube furthest away from its side tube was closed with calico, and a one-inch layer of coarse sand was introduced. The tube was then filled to within 2 inches of the outlet of the side tube with the air-dried soil under examination. The soil was poured into the tube through a metal funnel, and the tube dumped occasionally to ensure uniform packing. The tube thus contained, when filled, a column of soil of a length of 10 inches. Several such tubes, filled with different soils, were arranged in descending order in a battery. A slow stream of water was run into the tube at highest level. The water that did not percolate through the soil in this tube, accumulated until a head of height 2 inches above the level of the soil was attained. The surplus water then escaped from the side tube and entered the open end of the next soil tube at lower level, and so on throughout the battery. In this way, a constant head of water was maintained in each tube. The water which percolated through the soils was collected. Measurements of the volume of this water were made every two hours during three successive working days, and the results plotted in graphs. Usually six sets of observations on six different soils were made at one and the same time.

It has been shown by Green and Ampt[9] that determinations of the permeability of soils to water, made by observing the rate of *downward* flow, yield values which decrease in magnitude as the period of percolation increases. This has been accounted for partly by the fact that the finer particles are washed down by the moving water. They recommend that permeability determinations be made by measuring the rate of upward flow. Whereas this recommendation is justified in experiments with the majority of soils, the writer believes that, in case of soils, whose mechanical constitution is simple, i.e., soils which are composed mainly of one grade of soil particles, permeability determinations, made by measuring the rate of downward flow, yield results which are significant in comparative experiments. The actual records made with the Montserrat soils indicate that, when the soils have become thoroughly wetted, and when air has been displaced from their pore spaces, the rate of downward flow of water remains practically constant over a fairly prolonged period. Usually this period occurred during the second day of the experiments in the writer's experience. From curves, plotted with time and volume of water collected as co-ordinates, it was found possible to obtain constant and reliable values for the permeabilities of the soils under investigation. These values are recorded in column 8 of Tables I-IV. The formula used in arriving at the values is that given by Green and Ampt, i.e. $Pw = \frac{V}{t} \cdot \frac{l}{Ah}$

where Pw = the permeability constant; V = volume of water percolating in time t (seconds); l = length of column of soil, in cms.; A = area of section of soil column, in sq. cms.; h = head of pressure, measured from the bottom of the column.

It should be noted that the actual figures in column 8 are 100 time the numbers representing the permeability constants, as expressed in cc. per cc., of soil per second.

---

* These boxes (retention cups) may be obtained from the Central Scientific Co. 460, E., Ohio St.; Chicago., U.S.A.

5. Reaction.

This was estimated by Gillespie's method[8] briefly described in the writer's article on soil sourness, ([11], p.56). A neutral soil posesses a pH value of 7·0; an acid soil, a pH value numerically less, and an alikaline soil, numerically greater than 7·0.

6. Organic matter.

The total organic carbon was first estimated by the wet combustion method described by Watts ([26], p·31) In this method, the volume of carbon dioxide evolved when a known mass of the very finely powdered soil is warmed with a mixture of chromic acid and concentrated sulphuric acid is measured in a nitrometer containing mercury. From the volume of gas collected, the percentage of organic matter in the soil can be calculated. The percentage of organic matter in the soil is obtained by multiplying this result by 1·724

7. Soluble humus.

The percentage of humus soluble in ammonium hydroxide solution was estimated by the Grandeau method described by Hall ([10], p·166). Twenty grams of the soil are treated with dilute hydrochloric acid to remove carbonates. The soil is then thoroughly washed on a filter, and transferred to a bottle in which it is agitated with 550 c.c. of a 4 per cent. solution of ammonium hydroxide. After standing over-night, 150 c.c of the supernatant brown liquid are removed with a pipette, and evaporated to dryness in a weighed platinum dish over a water bath. The dish plus residue is weighed, and finally gently ignited to burn off the organic matter. The loss in weight is calculated back to the percentage loss on the original soil. This is taken to represent the percentage amount of ammonia-soluble humus in the soil.

Summary.

Part I.

1. Montserrat is composed of fragmentary volcanic material derived from igneous rocks of sub-alkaline type, chiefly hypersthene andesite.
2. This material has been consolidated into agglomerates, breccias and tuffs.
3. Erosion has produced several conspicuous *talus slopes* which occur chiefly in the southern part of the island. These consist of masses of loose debris overlying the consolidated rocks in layers of varying thicknesses. Water action has carved their surfaces into numerous ravines or ghauts.
4. In the northern part of Montserrat, the consolidated rocks appear near or at the surface, and constitute *shoal rock*. They have suffered intense denudation.
5. In accordance with the geological nature of the substratum, the soils of Montserrat may be classified into *talus soils* and *shoal soils*. The former are soils of transportation, and the latter, sedentary soils. They differ chiefly in the degree to which their subsoils provide free drainage.
6. The shoal soils may be subdivided into *humid upland soils*, *hilly land soils* and *valley soils*. The agencies that have given rise to these sub-types are mainly climatic and topographical in nature.
7. The chief physical features of the types and sub-types of soils enumerated are described in the text, and data obtained in a laboratory examination of representative samples of them are presented in tabular form.
8. The climatology of Montserrat is considered in some detail.

Part II.

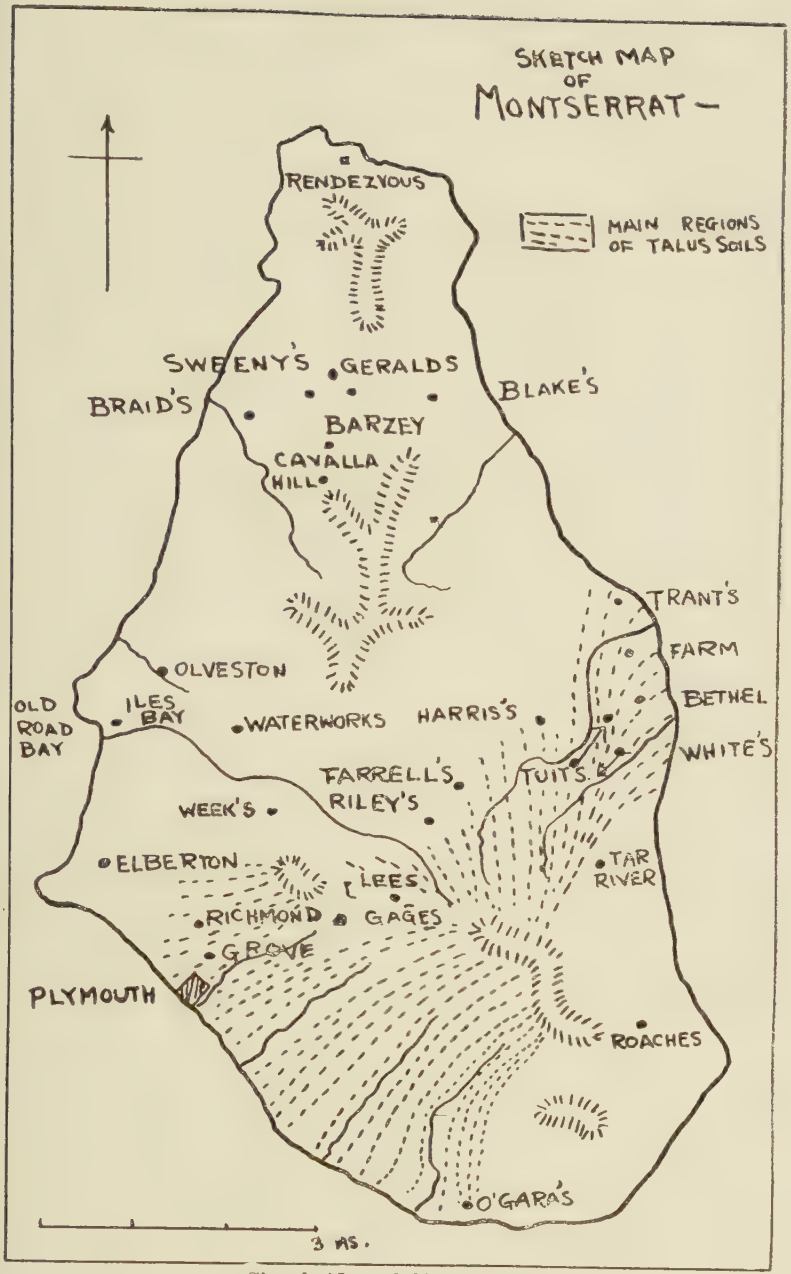
9. The problem of the *die-back of lime trees* in Montserrat is presented in historical and general outline
10. The recent view is that the die-back condition is the result of the effect of environmental factors on the growth of lime trees; the problem being physiological rather than parasitological.
11. The methods employed in, and the results obtained by a preliminary ecological reconnaissance of the die-back problemn in the West Indies are presented.
12. The main factors that might have bearing on the problemn are discussed. It is considered that the chief factors responsible for dieback are intimately connected with the water relations between the lime trees and their environment.
13. The effect of variations in water-supply on certain morphological features of lime trees are to be discussed in a separate article by the plant physiologist. (T. G. Mason).

Part III.

14. The outline is given of the laboratory methods used in the examination of soil samples collected in connexion with the investigation.

List of References.

1. Auchinleck, G. 'The measuremeat of shrinkage in soils *West Indian Bulletin*, XII, 1912, p. 50.
2. Bottomley, W. B. 'Some accessary factors in plan growth and nutrition.' *Proc. Roy. Soc.*; *Series B* 88, 1915, p. 237.
3. Bottomley, W. B. 'Some effects of organic growth-promoting substances on the growth of *Lemma minor* in mineral culture solutions' *Proc Roy. Soc.*; *Series B*, 89, 1916, p. 481.
4. Briggs, L. J., Jensen, C. A, and McLane, J. W. 'Mottle leaf of citrus trees in relation to soil conditions.' *Journ. Ag. Res.* VI, 1916, p. 721.
5. Briggs L. J., Jensen, C. A., and McLane, J. W. 'The mulched basin system of irrigated citrus culture, and its bearing on the control of mottle leaf.' U. S. Dept. *Agr. Bull.*, 499, 1917.
6. Egger, Baron H. F. A. 'The flora of St. Croix and the Virgin Islands.' *Bull., 13*, U. S. Nat. Mus. 1879.
7. Essig, E. O 'Die-back of citrus trees ; a physiological disease.' Pomona College: *Journ. Econ. Bot.* 1, p. 73.
8. Gillespie, L. J. 'Colorimetric determination of hydrogen-ion concentration.' *Soil Science*, IX, 1920, p. 115.
9. Green, H. W., and Ampt, G. A. 'Studies in soil physics. I, The flow of air and water through soils.' *Journ. Agr. Sci.*, IV, 1911, p. 1.
10. Hall, A. D. 'The soil.' London. *John Murray*, 1918.



Sketch Map of Montserrat.

11. Hardy, F. 'Soil sourness its meaning and significance. *West Indian Bulletin*, XIX, 1921, p. 37.
12. Hardy, F. 'The soils of Dominica, their genesis and fertility, considered in relation to reaction.' *West Indian Bulletin*, XIX, 1921, p. 86.
13. Harrison, J. B., Stockdale, F. A., and Ward, R. 'Sugar-cane experiments in British Guiana; Part II, The composition of soil water as affected by cultivation and manuring of the soil.' *West Indian Bulletin*, XIII, 1913, p 110.
14. Hilgard, E. W. 'Soils.' New York, *Macmillan*, 1918.
15. Hill, R. T. 'Evolution of the Windward Archipelago.' *Bul. Geol. Soc. Amer.*, XVI, 1905, p. 243.
16. Jensen, C. A. 'Humus in mulched basins; relation of humus content to orange production, and effect of mulches on orange production.' *Journ. Agr. Res.*, XII, 1918, p. 505.
17. Kellerman, K. F., and Wright, R. C. 'Relation of bacterial transformations of soil nitrogen to nutrition of citrous plants.' *Journ. Agr. Res.*, II, 1914, p. 101.
18. Lipman, C. B. 'The poor nitrifying power of soils as a possible cause of die-back in lemons.' *Science* (New series), 39, 1916, p. 728.
19 McCollum. 'The newer knowledge of nutrition.' *Macmillan*, 1919.
20. Macdonald W. 'Dry farming,' London, *T. Werner Laure* 1911.
21 Spencer, J. W., 'Geological and physical development of Antigua.' *Quart. Journ., Geol. Soc Lond.*, LVII, 1901, p. 491.
22. Suess, E. 'Das Antlitz der Erde' (The face of the earth). English translation by H. Sollas. Vol. I, 1904, p. 542,
23. Tempany, H. A. 'The soils of Antigua.' *West Indian Bulletin*, XV, 1915, p. 69.
24. Tempany, H. A. 'The shrinkage of soils.' *Journ. Ag. Sci'* VIII, 1917, p. 312. Reprinted in *West Indian Bulletin*, XVII, 1920, p. 50.
25 Tempany, H. A. and Jackson T. 'The lime industry in Antigua' *West Indian Bulletin*, XII, 1912 p. 1.
26. Watts, F. 'Soils of Dominica.' Publication of the Imp. Dept. Agr. for the West Indies, 1903.
27. Watts, F., and Tempany, H. A. 'The soils of Montserrat.' *West Indian Bulletin*, VI, 1905, p. 263.
28. Widtsoe, J. A. 'Dry farming.' *Macmillan*, New York 1919.

GROWTH AND CORRELATION IN SEA ISLAND COTTON.

BY T. G. MASON, M.A.

Economic Botanist and Acting Assistant for Cotton Research, Imperial Department of Agriculture for the West Indies.

Introduction.

The studies embodied in the present paper were undertaken in an attempt to ascertain how the growth processes in one part of the cotton plant are related to those in neighbouring parts. It was hoped that the investigation would prove of value not only to the physiologist, but that the results obtained would prove of assistance to the agronomist and the plant breeder.

It will be evident that there are two aspects to the problem. In the first place information is needed concerning the normal growth processes of the plant, and secondly, enquiry must be made as to how the normal course of development in one part is influenced by that in another. It will be patent that both the reproductive and vegetative phases of development ought to receive attention in any attempt which aspires to interpret the development of the organism as a whole. The general scope of the work can, however, be rendered more intelligible after a brief survey has been made of the arrangement of the branch system of the Sea Island cotton plant.

The Arrangement of the Branches.

The plant consists of a central-axis bearing a single leaf at the end of each internode. The leaves are arranged in a $\frac{2}{5}$-spiral. On some individuals the direction of the spiral is right-handed, and in others left-handed; the significance of this condition of antidromy has not yet been elucidated. In the axil of each leaf a bud is present, to one side of it, either to the right or left, according to the direction of the leaf spiral, is another bud. From this extra-axillary bud all the branches are normally developed, the axillary bud remaining either completely dormant, or producing branches of much reduced size. Removal of the branches arising from the extra-axillary buds of course permits their further development.

The dimorphism of the branches is normally well marked, the two types being segregated on distinct parts of the central-axis. The fruiting-branches are first developed somewhere towards the basal region, generally about the ninth node, and extend upwards to the apex. The central-axis and its attendant fruiting-branches will be termed the central-axis system. Reference to Plate 1 will render this intelligible.

The vegetative branches, which normally number from two to four, have their origin in the extra-axillary buds of the nodes immediately below the first fruiting-branch. They are in all

respects exact counterparts of the central-axis system, and will be termed the vegetative-branch systems.

The fruiting-branches bear at the end of each internode a flower-bud, or square as it is sometimes termed, which is situated on the branch in a position nearly opposite the petiole of the leaf. The flower-buds have been considered homologous to the extra-axillary buds from which the fruiting-branches arise. The axillary buds of the fruiting-branches frequently give rise to secondary fruiting-branches (cf. Plate 2), or sometimes to vegetative-branches of much reduced size.

Briefly, then, the plant may be said to consist of a central axis and its associated system of fruiting-branches, and basally a variable number of vegetative-branches, each of which supports a number of fruiting-branches in a manner exactly similar to the central-axis.

Experimental.

The work was carried out on a group of plants, grown for the purpose, on the Experiment Station, St. Vincent. The variety selected for the purpose was isolated by Dr. Harland, and is probably the type best adapted to the very humid conditions under which cotton is grown in St. Vincent. The population consisted of 130 plants, spaced at a distance of 4 feet from one another. The vegetative-branches were removed from alternate plants. As a result of damage sustained by the branches, which was mainly the work of a gale of wind on September 8, the number of plants was finally reduced to 106, so that there remained fifty-four plants in the pruned class and fifty-two in the unpruned. In order to render the subterranean moisture and temperature conditions as uniform as possible, a heavy mulch of cane leaves (*Saccharum officinarum*) was distributed throughout the experimental plot.

The plants were spaced far apart from one another in order that their development should not be influenced by competition between neighbouring plants for light, water, or soil solutes. The wide spacing presents an additional advantage, in that the vegetative-branches tend to grow out from the central axis nearly horizontally, and do not therefore function as a hedge excluding light from the lower fruiting-branches. The possible effect of competition for water and soil solutes between the basal branch systems and the central axis system of the unpruned class is difficult to gauge, and will require further consideration. Another factor that will merit attention when contrasting the development of the central-axis system of the two classes is the effect of those correlation-factors which manifest themselves, for example, in the condition of dominance and subordination of buds. Discussion of their nature will be deferred until the results have been presented.

The Growth Rates.

The length of the central-axis was determined weekly. The measurements were made from an ink mark, situated approxi-

mately 3 centimetres above the surface of the ground, to the apical bud. The first measurements were made on July 8, seventeen days after sowing. On this day the mean distance between the ink mark and the apical bud was 6·8 ± ·10 with a coefficient of variability of 16·1 ± 1·07 in the pruned class, and 6·9 ± ·10 with a coefficient of variability of 16·0 ± 1·09 in the unpruned. The

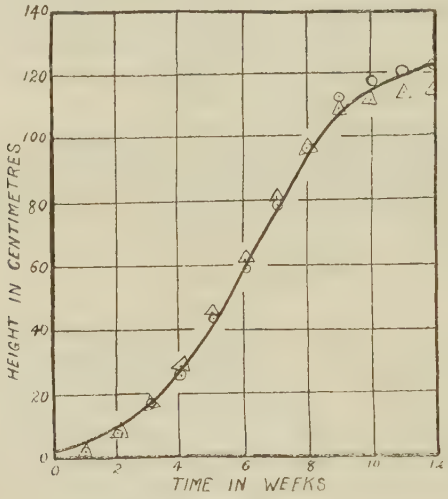


FIG. 1.

Rate of Axis elongation.

The curve represents computed values; points within circles show observed values for the pruned class, and points within triangles for the unpruned class.

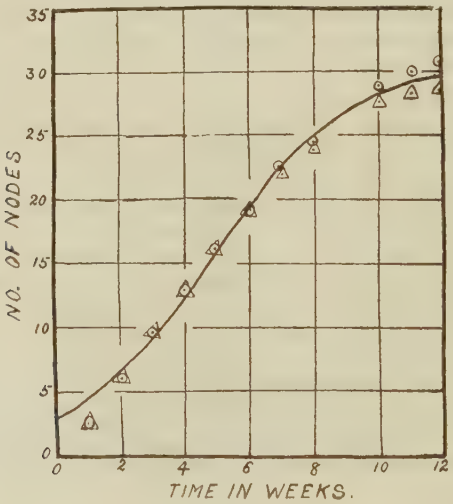


FIG. 2.

Rate of Node production.

The curve represents computed values; points within circles show observed values for the pruned class and points within triangles for the unpruned class.

results reported in Table I* represent the amount of growth made subsequently.

The rate at which leaves, and therefore nodes, were laid down by the apical meristem of the central-axis was also reckoned weekly, only leaves which had escaped from the apical bud and whose upper surface was visible, were recorded in these determinations. The first record was made on July 8. On this day the pruned class had 5·4 ± ·05 nodes with a coefficient of variability of 10·4 ± ·96, and unpruned 5·2 ± ·06 with a coefficient of variability of 13·2 ± 1·22. The results tabulated (Table II) represent the mean number of nodes produced subsequently on the central-axis.

The rate at which flower-buds accumulated on the fruiting branches of the central-axis system may be seen by reference to Table III. As a very nearly constant time-relation apparently exists between the emergence of the foliage leaf on the fruiting-branch and the appearance of the flower-bud, it was decided to exclude from the determinations flower-buds whose attendant foliage leaves had not developed sufficiently to render their upper surfaces clearly visible. By adopting this convention, buds below a certain age have been eliminated from the results.

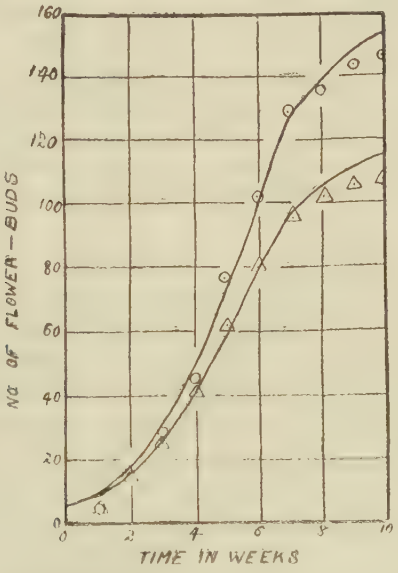


FIG. 3.

Rate of Flower-bud production.

The curves represent computed values; points within circles show observed values for the pruned class, and points within triangles for the unpruned class.

*The tables are grouped together at the end of the paper. The complete data, which is of too extensive a nature for publication, will be sent to other workers, who may be interested.

It should be noted that a certain number of flower-buds are produced on the secondary fruiting-branches (cf. Plate 2), and that these, too, figure in the results.

Inspection of Figures 1 and 3, in which the results for axis elongation and flower-bud accretion are shown graphically, demonstrates that the growth-rates were slow initially, became quicker, and then declined. Such an s-shaped course is characteristic of an autocatalytic reaction. The hydrolysis of sucrose is a type of this class of reaction. The rate is retarded at first by a lack of catalyst, and at the end by a deficiency of substrate; the latter diminishing the rate as a result of mass action. Recently Reed and Holland[3] have shown that the rate of stem elongation in Helianthus approximates closely the course of an autocatalytic reaction. As a result of this correspondence between the growth-rate and a monomolecular reaction, Reed[4],[5] has suggested that growth is some sort of a catalytic process, and that consequently, the organism may be regarded as the end-product of a reaction in which a catalyst acts upon a substrate.

The initial lag in the growth-rate of the nodes is not so marked as in the rate of axis elongation and flower-bud accretion. It will be of interest nevertheless, to inquire how closely the experimental results approximate the values calculated from the differential equation

$$\frac{dx}{dt} = k\,x\,(a-x)$$

which is characteristic of an autocatalysed reaction. In this equation x represents the length of the central-axis, the total number of flower-buds or of nodes at any time t; a is the final height, number of buds or of nodes as the case may be; and k is a constant. When integrated the above equation becomes

$$\log.\frac{x}{a-x} = K\,(t-t')$$

where $K = ak$ and t' is the time at which the central axis has grown to half its final length, or at which half the number of flower-buds or of nodes have been formed, that is to say, when $x = \frac{a}{2}$. By means of tables prepared by Robertson[6], the constants K and the theoretical values of x are readily obtained from the observed values. The values taken for a and t', and also the derived values of K, may be seen in Tables I, II, and III. It will be observed that the calculated curves (Figures 1, 2, 3) which are constructed from the computed values, agree remarkably closely with the experimental data. The rate of the node production is, however, practically linear for the first five or six weeks, and is not therefore especially suggestive of autocatalysis. Though the correspondence between the observed and the theoretical values is admittedly very striking, yet the assumption that growth is some sort of a catalytic process is quite unwarranted. An examination, for example, of the time-relations of the rates of axis elongation and flower-bud formation lends no support to this hypothesis. This will be considered in the next section.

The Weekly Increments in Growth.

The amount of elongation observed in the central-axis at intervals of seven days is recorded in Table IV. In Tables V and VI the weekly rates of flower-bud and flower production will be seen. The data are presented graphically in Figure 4. Inspection of the graphs demonstrates very clearly the retardation in growth-rate of the central-axis which attends the initiation of

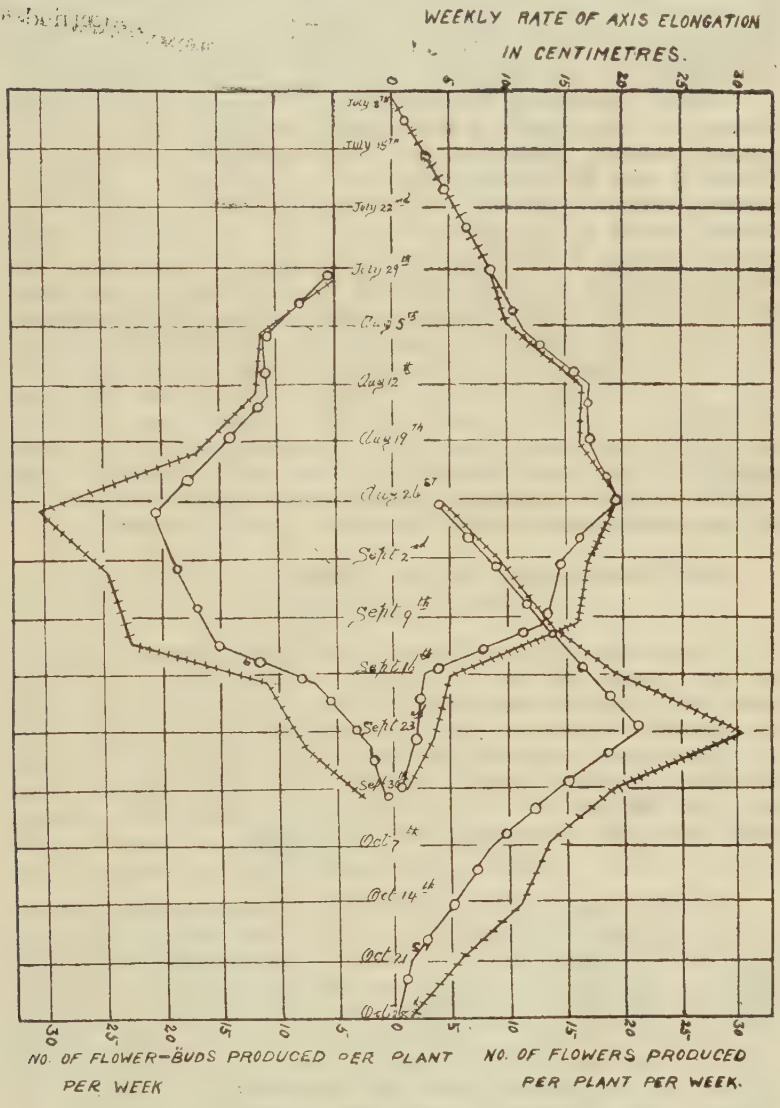


Fig. 4.

Showing weekly rate of axis elongation, flower-bud and flower production. Unpruned Class —o—o—o—. Pruned Class —|—|—|—|—.

flower formation and consequently of fruit development. This cannot be considered indicative of the action of a catalyst on a substrate, or that the decline in the growth-rate is due in any way to mass action. It does suggest that senescence in the central-axis of the cotton plant is associated with a downward translocation of carbohydrates, and probably other growth-promoting substances, from the apical region of the system to the basal fruiting-branches on which the first fruits are developed. The lag at the commencement of the growth period is doubtless the result of a smaller number of elongating internodes, and a relative paucity in the carbohydrate supply, the inevitable consequence of the development of the photosynthetic system.

Before considering the developing of the central-axis branch systems of two classes, a word should be said concerning the relative rates of flower-bud and flower production Reference to Tables V and VI will show that the rate of flower production exceeded that of flower-bud production in the third and fourth weeks in the pruned class, and in the third, fourth and fifth weeks in the unpruned. An excess of flower-buds over flowers might of course be ascribed to shedding of flower-buds, but how, it will be asked, can the reverse occur. On the assumption that the convention adopted in reckoning flower-buds was justified, and that consequently, the observed rates of flower-bud accretion are not less reliable than those of flower production, it would seem that the greater rates of flower production may have been due to a shortening of the period required for the maturation of the flower. As the subject is one which will receive attention elsewhere, and is beyond the scope of the present paper, further discussion is unnecessary.

The Development of the Central-Axis System in the Two Classes.

The results attending the removal of the vegetative-branches will be considered. The contrast between the rates of development of the central-axis system in the two groups is shown by the graph in Figure 5. The curves represent the relative rates of development between the two classes, and are of course obtained by plotting out their ratios. It will be evident, that had the removal of the vegetative branches been without effect upon the development of the central-axis system, the curves in Figure 5 ought to have approximated a straight line.

At this stage of the enquiry a word should be said concerning the manner and time of pruning. The young vegetative branches were removed the day prior to that on which the first reckoning of the number of nodes was made, that is to say on July 29. At this period these branches ranged from 0·14 centimetres in length. The shoots, which, as a result of the pruning, commenced to develop from the axillary buds, as well as from the extra-axillary buds, were removed at the end of the ensuing week. The last pruning was carried out on August 12, and consisted mainly in the removal of vegetative branches originating in the axillary buds in the zone of basal fruiting

branches. All the upper axillary buds, when developing at all, produce greatly reduced fruiting branches. In some strains, however, the axillary buds give rise almost exclusively to small vegetative branches; this character, it may be noted, is one of considerable cultural importance under humid conditions. The period of pruning thus extended over a period of three weeks, and is noted in Figure 5 by a series of crosses.

Inspection of the graph will show that the rate of node production in the pruned class, which prior to the removal of the vegetative branches had been somewhat less than in the unpruned, exceeded the latter on the fourth week. This augmented rate of node production was naturally followed by a greater rate

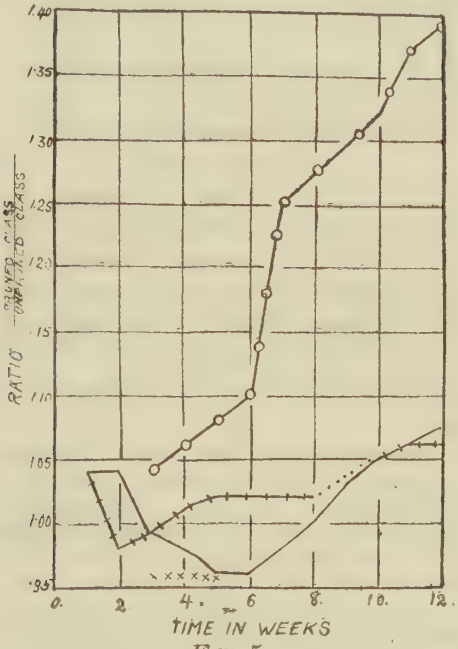


FIG. 5.

Exhibiting relative rates of growth in two classes.

Flower-bud Accretion —o—o—o—
Node Production —|—|—|—|—|—
Axis Elongation ———
Period of pruning xxxxxx

of stem elongation as a result of the greater number of elongating internodes.

Flower-bud production in the pruned class exceeded that in the unpruned throughout the period, but did not display a very marked superiority until the seventh week.

The rate at which flower-buds were produced by the axillary fruiting branches was not ascertained; it may be noted though, that the mean number of flowers produced on these branches by

the plants receiving pruning was 5·6 ± ·55 with a coefficient of variability of 81·3 ± 8·03, whereas in the unpruned class the number was 3·6 ± ·29, and the coefficient of variability was 98·8 ± 11·21.

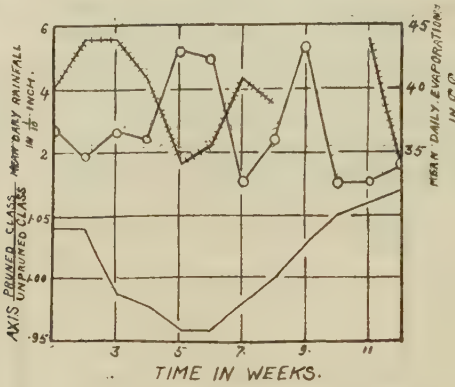


FIG.6.
Showing relative rates of axis elongationin the two classes.—Rainfall—o—o—and Evaporation—|—|—

To sum up, the removal of the vegetative-branches resulted in a greatly increased production of flower-buds, and of somewhat higher rates of axis elongation, and of node production. It will already have been noted (cf. Tables IV, V, and VI) that the pruning did not produce any marked change in the variability of the population.

It will be profitable at this juncture to compare the relative rates of axis elongation in the two classes with the fluctuations in the aridity of environment. A priori considerations suggest that the growth-rate of the group with adherent vegetative branches would have been checked relative to that of the pruned plants during the periods of decreasing humidity. The weekly rates of evaporation from the Livingston black spherical atmometer, and of precipitation, both of which are expressed on the daily basis, are shown in Figure 6 for comparison with the curve showing the relative rates of central-axis elongation in the two classes. The rates of evaporation were not available for the eighth and ninth weeks.

Inspection of these curves will make it clear that the additional water strain which might have been anticipated from the presence of the vegetative-branch systems, has been responsible for no sensible retardation of the growth-rate of the unpruned class during the periods of greatest aridity. It may accordingly be surmised that the reduced development of the central-axis of the unpruned class was not due to a water shortage, or to any factor associated with competition for water between the different parts of the plant. I should also be observed that the rates of node production and flower-bud

formation bear no constant relation to the changes which occurred in the aridity of the environment.

The Number of Nodes on the Fruiting-Branches.

Morphogenetic considerations suggest three factors to which the augmented rates of flower-bud production in the pruned class could be ascribed. Firstly it will be patent that the greater rate of node production in this class, to which reference was made in the preceding section, must have involved a concomitant acceleration in the rate of fruiting-branch formation for fruiting-branch development, when once initiated, takes place from the extra-axillary buds of every node of the central-axis.

The second factor, responsible for the difference in the rates of flower-bud formation in the two groups, was a greater development in the pruned class of secondary fruiting-branches (cf. Plate 2). The mean number of flower-buds produced per plant

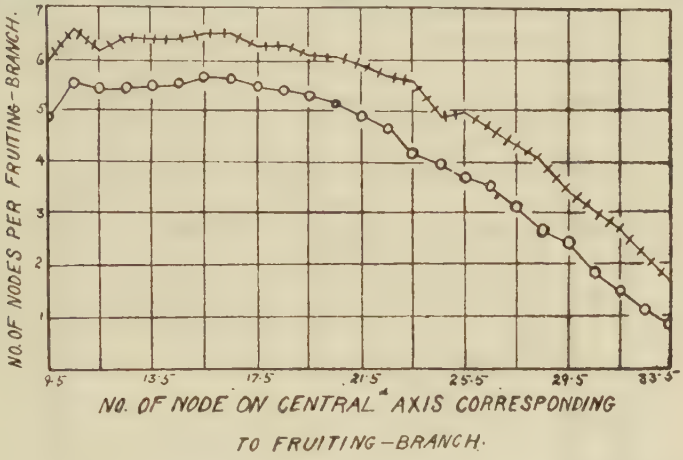


Fig. 7.

Showing mean number of nodes on successive fruiting-branches in the two classes. Unpruned :— —o—o—o— Pruned :— —|—|—|—|—

on these branches in the latter class was 17·9, whereas in the unpruned class there were only 2·0.

The most important factor, however, may be traced to a larger number of nodes on the individual fruiting-branches; for at every node on the fruiting-branches, it will be remembered, there is a flower bud. The number of nodes on successive fruiting-branches is shown in Table VII; the results are presented graphically in Figure 7. It will be observed that the pruned class exhibits a well marked superiority over the unpruned in this respect. A perfectly regular decline in the number of nodes of the apical fruiting-branches will also be detected. These observations naturally prompt inquiry as to the nature of the factors which determine the number of nodes on a fruiting-branch. Any

hypothesis which may be formulated ought not only to explain why there is a reduction in the number of nodes on the apical fruiting-branches, but should also account for the reduction in the number of nodes, which is associated with the development of the vegetative-branches. This is evidently another phase of the problem presented by the decline in the growth-rates of both classes, and by the augmented development of the central-axis system of the group that received pruning.

Coefficients of Correlation between the Number of Nodes on Neighbouring Fruiting-Branches.

The degree of correlation between the number of nodes on neighbouring fruiting branches will now be considered. The coefficients have been calculated, and are recorded in Table VIII. The results are presented graphically by overlapping means in Figure 8. It will be observed that the coefficients are all positive and many times their probable errors. It will also be seen that'

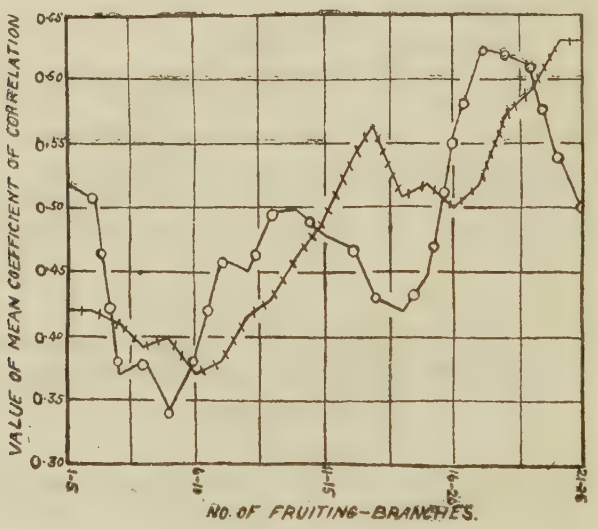


Fig. 8.

Showing mean value of coefficient of correlation for successive over lapping groups of five fruiting-branches.

there is a well-defined tendency in both groups for the correlation between the number of nodes on neighbouring fruiting-branches to be greater in the apical zone of fruiting-branches, where of course the number of nodes on the fruiting-branches is less than in the lower zones. This and the positive nature of the coefficients may be held to indicate the presence of a factor, which limits the number of nodes on all the fruiting-branches and that its influence becomes more marked on the fruiting-branches in the apical region. If this correlation-factor is associated with the development of fruit by the lower fruiting-branches, it would seem that the development of the latter, too, is limited by their

own activity in producing fruit. In short, it would appear that the number of nodes on a fruiting-branch is determined by the development of fruit both on itself and on the other branches of the system. This view is supported by the fact that the removal of fruit results in the greater increase in the number of nodes on the fruiting-branches It is of some importance to note that the natural shedding of fruit may tend, under certain conditions, to bring about the same result; this, it is patent, is but an illustration of what has long been known under the name of 'compensatory growth.'

Thus far no attempt has been made to account for the more limited development of the fruiting-branches in the group of plants with adherent vegetative-branches. Though the reduction in the number of nodes on the fruiting-branches in the apical region of the central-axis system has been associated with the development of fruit on the lower fruiting-branches, yet there are objections to ascribing the more limited development of the fruiting-branches of the central-axis system of the unpruned plants to the production of fruit by the vegetative branches. The main objection of course is that the pruned class exhibited a well-marked superiority in the production of flower-buds before the appearance of fruit on the vegetative-branches of the unpruned group. It seems necessary to assume, therefore, that the development of the vegetative branches, irrespective of the development of fruit, in some way introduces a factor which limits the development of the fruiting-branches of the central-axis system. It is of interest in this connexion to note that the coefficients of correlation between the basal fruiting-branches tend to be somewhat smaller in the unpruned group. This is possibly the expression of a factor, introduced by the growth of the vegetative branches, which inhibits fruiting-branch development.

The Rate of Axis Elongation in the Absence of Developing Fruit.

The substance of the preceding sections may now be summed up. The decline in the development of the fruiting-branches in the apical region of the central-axis system, the retardation, in the rate of axis elongation, or of node production by the apical meristem, may all be traced to the presence of a common factor introduced by the development of fruit on the basal fruiting-branches. The senescence of the central-axis system as a whole seems to find its most ready interpretation in this way, and need not therefore be ascribed to the action of a catalyst on a substrate. On the other hand the reduction in the development of the central-axis system resulting from the presence of the basal vegetative-branches systems, cannot be specifically associated with fruit development by the latter, but must be ascribed, at least in part, to the mere vegetative development of these branches. It becomes essential, therefore, to enquire whether the decline in the growth-rate of the central-axis is necessarily dependent on the development of fruit, or whether it may not occur as the

result of the vegetative development of fruiting-branches from which fruit production has been prevented, by the removal of flowers.

The plants employed in this experiment were approximately eleven weeks old at the time the measurements first recorded were made. All flowers, fruit, and vegetative-branches had been removed nine days previously. There were ten plants in

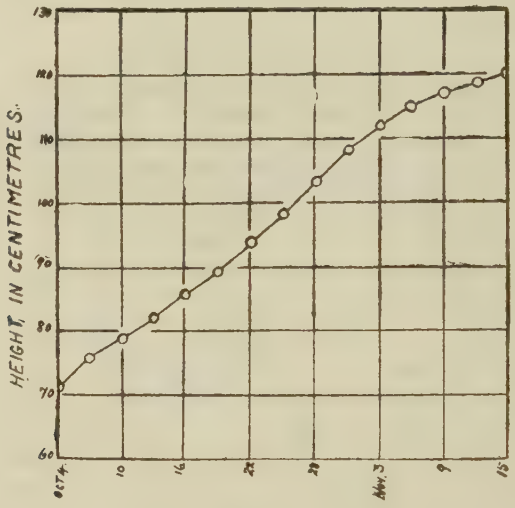


FIG. 9.

Growth-rate of plants from which flowers and fruit were removed.

all, and the measurements were made daily for a period of forty-three days; flowers were removed daily as they appeared, so that there were no developing fruit on the plants. The results are presented graphically for three day intervals in Figure 9. The fruiting-branches as a result of the flower pruning, of course, developed a much larger number of nodes than would normally have occurred. Reference to the graph will show that even in the absence of developing fruit a sensible decline occurred in the growth-rate, though this was admittedly considerably less pronounced than if flowers had not been removed. It may be therefore tentatively concluded that a decline in the growth rate is not necessarily associated with fruit development, but may occur solely as the result of the vegetative development of the fruiting-branches.

DISCUSSION.

Before discussing the significance of the results reported in the preceding sections, it will be well, in order to remove any possible confusion in the mind of the reader, briefly to state again their contents.

Two groups of cotton plants were grown, from one of which the vegetative-branches were removed The rate of development of the central-axis system was compared in the two groups. The three phases of growth which were considered, were the elongation of the central axis, the production of nodes by the apical meristem of the central-axis, and the formation of the flower-buds on the fruiting-branches. In all three cases the experimentally obtained values, for both groups, were in good agreement with the theoretical values computed from the equation charateristic of an autocatalytic reaction.

It was emphasized that the mere correspondence between the observed and the computed values could not warrant the conclusion that growth was some sort of a catalytic process; or to state the case in other terms, that organism was the end-product of a reaction in which a catalyst acted upon a substrate. The decline in the growth-rate of the central-axis, which accompanied the initiation of fruit production seemed to suggest, on the contrary, that senescence of the central axis system was associated with a downward translocation of carbohydrates, and possibly other growth-promoting substances, from the apical region to the developing fruit. The latter explanation, it may be remarked, involves the assumption that the cessation of activity in the apical meristem is due to the existence of a correlating factor of some sort, which operates to deflect the supply of assimilates from the apical bud to the developing fruit; and that consequently, renewed activity of the apical bud should attend ts isolation from the growth-inhibiting influence of the developing fruit. It is of some interest, therefore, to find that the apical bud does exhibit renewed activity when 'budded' on to a young cotton plant.

The removal of the vegetative-branches was found to permit, a somewhat more rapid rate of axis elongation and of node production. The rate of flower-bud formation in the pruned class was shown to be considerably greater than in the unpruned. Examination of the fruiting-branches revealed the fact that this was chiefly the result of a greater number of nodes on the ndividual fruiting-branches.

It was also ascertained that the decline in the rates of axis elongation and of node production by the apical meristem of the central-axis, which was exhibited by both groups, was accompanied by a perfectly regular reduction in the degree of development of the apical fruiting-branches. This and the more limited development of the fruiting branches of the group of plants with adherent vegetative-branches prompted enquiry into the nature of the factors limiting fruiting-branch development.

Calculation of the coefficients of correlation between the number of nodes on neighbouring fruiting-branches demonstrated that not only were the coefficients all positive, but that their values were, on the whole, greater in both groups for the apical than for the basal zone of fruiting branches This was considered to indicate the presence of some factor which tended to limit the development of all fruiting-branches, and that its influence

became more marked as development proceeded. Is was accordingly suggested that the development of all the fruiting-branches was limited, on the one hand, by their own activity in producing fruit, and that the more reduced development of the apical fruiting-branches was due to the influence of fruit maturing on the basal fruiting-branches. This view seemed to find support in the observation, that the removal of the flowers as they appeared, and consequently the absence of developing fruit, resulted in a more extended development of the fruiting-branches.

Comparison of the coefficients of correlation in the two classes showed that their values were initially somewhat smaller in the group from which the vegetative-branches had been removed. This and the more reduced development of the fruiting branches in this class suggested the introduction of an additional factor, inhibiting the development of the fruiting branches in the unpruned class. It was emphasized that the more limited development of the fruiting-branches in this class could not be specially associated with the development of fruit on the vegetative-branches. By daily measurements of a group of plants from which all vegetative-branches and fruit had been removed, it was found that the decline in the growth rate of the central-axis, though deferred, was none the less marked; from which it was tentatively concluded that the mere vegetative growth, either of the fruiting-branches or of vegetative-branches, exerted a retarding effect on the growth of the central-axis.

The nature of the growth-inhibiting factor, to which the growth correlations just described have been referred, must now be considered. It was shown that the more limited development of the central axis in the group of plants with adherent vegetative-branches could not be ascribed to a greater water strain than that which prevailed in the pruned group, even though, as was pointed out, a more pronounced water-shortage might legitimately have been expected as the result of the greater transpiring surface due to the presence of the vegetative-branch systems.

Nevertheless, it might possibly be argued, that competition for inorganic electrolytes in the ascending sap between the branch systems might have been responsible for the more limited development of the central-axis system of the unpruned plants. It might also appear feasible to explain the reduced development of the apical portion of the central-axis system in both groups as being due to a prior claim by the basal fruiting-branches and their developing fruit on the supply of inorganic solutes in the ascending sap. It will be evident that this hypothesis assumes, since the view that competition for water was found untenable, that the solutes and solvent, which constitute the soil solution, move independently upwards after their entry into the plant. Though such an assumption presents obvious difficulties, it cannot be easily dismissed It would not therefore be unjustifiable to conclude from this line of argument that the experimental results might be reconciled with the hypothesis, that

growth, whether in the apical portion of the central axis system of both groups, or in the central-axis of the pruned group, was checked as a result of a limited supply of electrolytes. Difficulties, however, are encountered when the attempt is made to harmonize this view with the fact that the coefficients of correlation between neighbouring fruiting-branches were greater in the apical than in the basal region of the central-axis system. The assumption that the reduced development of the apical region is due to the production of a growth-inhibitor by the basal fruiting-branches, and that the more limited development of the central-axis system of the unpruned groups is due to the production of a growth-inhibiting substance by the vegetative-branches, is fraught with even greater difficulties than those attending the electrolyte hypothesis. The chief objection to this assumption is of course that the growth-inhibitor should depress growth wherever it is produced, for there it ought also to be in greatest concentration.

It would seem more plausible to assume that the growth promoting substances tend to be withdrawn from the central axis system as a result of the unrestricted growth of the vegetative branches, and that the senescence of the central axis system is similarly ascribable to deflection of these substances to the basal fruiting-branches. Harvey [1] has suggested that these growth-promoting substances may include such bodies as the chromogens of Palladin, which are produced by all cells, and are diffusible. There can be little doubt that the movement of such substances is intimately associated with the translocation of carbohydrates.

Though the existence of such substances would doubtless account for the correlation in the growth processes which have been considered in the course of these studies, it will be evident that, until their nature, and the mechanism of their translocation have been elucidated, further speculation cannot be profitable.

Summary.

(1)—The development of the central-axis system of branches was studied in two groups of cotton plants, from one of which the vegetative-branch systems were removed.

(2)—The rate at which the central-axis elongated, of node production by the apical meristem, and of flower-bud formation on the fruiting-branches, was found in all three cases to approximate closely the course of an autocataly tic reaction.

(3)—It was emphasized that the simulation of an autocatalytic reaction was probably quite illusory. Examination of the coefficients of correlation between the number of nodes on neighbouring fruiting-branches suggested, on the contrary, that the decline in the growth rate of the central-axis system was due to the presence of a correlating-factor. The latter was associated with the development of fruit on the basal fruiting-branches, and to a lesser extent with the vegetative growth of these branches.

(4)—The removal of the vegetative-branches resulted in a greater development of the central-axis system.

(5)—It was found impossible to harmonize the more limited growth of the central-axis system, exhibited by the unpruned group, with the view that development was checked, as a result of competition with the vegetative-branches for either the solutes or the solvent of the soil solution.

(6)—It was suggested that not only the more limited development of the unpruned group, but also the decline in the growth-rate of both groups, was due to the removal of growth-promoting substances by the vegetative-branches and the basal fruiting-branches respectively. It was pointed out that the movement of these substances was probably associated with the translocation of carbohydrates.

Literature Cited.

(1) Harvey, R. B. Relation of Catalase, Oxidase, and H + Concentration to the Formation of Overgrowths. *Amer Journ. of Bot.*, Vol. VII, pp. 211-21, 1920.

(2) Reed, H. S. and Halma, F. F. The Evidence for a Growth-Inhibiting Substance in the Pear Tree. *Plant World.* Vol 22. p.p. 239–47, 1919.

(3) Reed, H. S. and Holland, R. H. The Growth Rate of an Annual Plant, Helianthus. *Proc. Nat. Acad. Sci.*, Vol. 5, pp. 135-44, 1919.

(4) Reed, H. S. The Dynamics of a Fluctuating Growth Rate. *Proc. Nat. Acad. Sci.*, Vol. 6, pp. 397-410, 1920.

(5) Reed, H. S. Slow and Rapid Growth. *Amer. Journ. of Botany*, Vol. VIII, pp. 327-33, 1920.

(6) Robertson, T. B. Tables for the Computation of Curves of Autocatalysis, with Especial Reference to Curves of Growth. *Univ. Cal. Publ. in Physiology*, Vol. 4, pp. 211-28, 1915.

Arrangement of Branch Systems in Cotton Plant.

PLATE 1

Primary Fruiting-branch with Secondary Fruiting-branch.

PLATE 2

TABLE I.—AXIS ELONGATION.

Date.	t weeks.	x observed pruned class.	x observed unpruned class.	x calculated a = 126 t' = 6·1 K = ·26
July 8 ...	0	0	0	3·2
,, 15 ...	1	2·8	2·7	5·7
,, 22 ...	2	8·5	8·2	9·9
,, 29 ...	3	17·0	17·1	17·0
August 5 ...	4	27·4	28·1	27·9
,, 12 ...	5	43·7	45·3	43·0
,, 19 ...	6	60·1	62·3	61·1
,, 26 ...	7	79·8	81·8	79·6
Sept. 2 ...	8	97·1	96·8	95·4
,, 10 ...	9·14	113·0	109·9	108·5
,, 16 ...	10	117·7	112·3	114·9
,, 23 ...	11	121·3	114·4	119·6
,, 30 ...	12	122·3	114·8	122·5

TABLE IV.—WEEKLY INCREMENTS OF AXIS ELONGATION.

Date.	Pruned class.		Unpruned class.	
	Weekly increments.	Coefficient of variability.	Weekly increments.	Coefficient of variability.
July 15	2·8 ± ·08	29·8 ± 2·10	2·7 ± ·10	37·7 ± 2·83
„ 22	5·7 ± ·15	29·4 ± 2·07	5·5 ± ·17	32·1 ± 2·32
„ 29	8·5 ± ·17	21·3 ± 1·44	8·9 ± ·20	24·4 ± 1·71
August 5	10·4 ± ·16	17·4 ± 1·16	11·0 ± ·17	15·8 ± 1·07
„ 12	16·3 ± ·21	14·1 ± ·93	17·2 ± ·22	13·6 ± ·92
„ 19	16·4 ± ·12	7·8 ± ·50	17·0 ± ·16	9·8 ± ·65
„ 26	19·7 ± ·18	9·9 ± ·64	19·5 ± ·14	7·5 ± ·50
Sept. 2	17·3 ± ·28	18·0 ± 1·21	15·0 ± ·27	19·3 ± 1·32
„ 10	15·9 ± ·32	22·1 ± 1·50	13·1 ± ·31	26·6 ± 1·88
„ 16	4·7 ± ·25	55·9 ± 4·63	2·4 ± ·16	69·3 ± 6·42
„ 23	3·6 ± ·19	54·9 ± 4·51	2·1 ± ·13	68·9 ± 6·35
„ 30	1·0 ± ·21	131·1 ± 13·85	·4 ± ·06	150·6 ± 23·44

TABLE V.—WEEKLY INCREMENTS OF FLOWER-BUD ACCRETION.

Date.	Pruned class.		Unpruned class.	
	Weekly increments.	Coefficient of variability.	Weekly increments.	Coefficient of variability
July 30	5·5± ·30	59·0± 4·99	5·3±·32	64·2± 5·74
August 6	11·6± ·28	25·9± 1·79	10 9±·35	34·0± 2·49
„ 13	12·1± ·24	21·9± 1·49	10 7± 30	29·5± 2·11
„ 20	17·0± ·38	24·2± 1·66	15·0±·32	22·8± 1·59
„ 27	30·8± ·98	34·8± 2·52	19·9±·70	36·2± 2·68
Sept. 3	25·2±1·03	44·5± 3·42	18·7±·78	44·4± 3·47
„ 12	23·0±1·01	48·0± 3·76	15·6±·70	47·8± 4·60
„ 17	11·2± ·58	56·9± 4·74	7·1±·52	80· ± 8·01
„ 24	8·0± ·61	82·5± 8·22	2·3±·26	122·0±15·89
October 1	2·5± ·36	150·7±22·83	·4±·08	281·5±76·17

TABLE VI.—WEEKLY INCREMENTS IN FLOWER FORMATION.

Date.	Pruned class.		Unpruned class.	
	Weekly increments.	Coefficient of variability.	Weekly increments.	Coefficient of variability.
August 26	4·3±·23	58·7± 4·95	3·9 ± ·21	57·9± 4·86
Sept. 2	9·2±·30	35·3± 2·56	8·8±·34	42·5± 3·22
„ 9	13·3±·30	24·9± 1·71	12·2±·36	30·9± 2·18
„ 16	19·5±·38	21·3± 1·44	17·3±·42	26·5± 1·84
„ 23	30·3±·70	25·2± 1·73	21·6±·61	30·6± 2·16
„ 30	19·0±·49	28·0± 1·95	14·2±·38	29·4± 2·07
Oct. 7	13·3± 49	4·03± 3·00	8·5± 45	57·3± 4·79
„ 14	11·0±·59	58·4± 4·92	5·0±·38	83·1± 8·32
„ 21	5·5±·49	86·9± 8·93	1·3±·20	165·7±27·39
„ 28	1·4± 23	176·4=30·75	·3±·06	268·3±68·28

TABLE VII.—NUMBER OF NODES ON SUCCESSIVE FRUITING-BRANCHES

No. of fruiting-branch.	Pruned class.		Unpruned class.	
	Mean No. of node on central axis from which fruiting-branch was developed.	Mean No. of nodes on fruiting-branch.	Mean No. of node on central-axis from which fruiting-branch was developed.	Mean No. of nodes on fruiting-branch.
1	9·5	5·9 ± 11	9·3	4·8 ± ·12
2	10·5	6 6 ± ·06	10·3	5·5 ± ·10
3	11·5	6·2 ± 06	11·3	5·4 ± ·07
4	12·5	6·4 ± ·07	12·3	5·4 ± ·09
5	13·5	6·3 ± ·07	13·3	5·5 ± 07
6	14 5	6·4 ± ·07	14·3	5·5 ± ·07
7	15·5	6·5 ± ·08	15 3	5·7 ± ·07
8	16·5	6·5 ± ·07	16·3	5 6 ± ·08
9	17·5	6·3 ± ·09	17·3	5·5 ± ·03
10	18·5	6·3 ± ·08	18·3	5·4 ± ·08
11	9·5	6·1 ± ·11	19·3	5·3 ± ·09
12	0·5	6·2 ± ·10	20·3	5·2 ± ·11
13	1·5	5·9 ± ·10	21·3	4·9 ± ·08
14	2·5	5·7 ± ·10	22·3	4·7 ± ·10
15	3·5	5·6 ± ·10	23·3	4·2 ± ·09
16	4·5	4·9 ± ·12	24·3	4·0 ± ·11
17	5 5	5·0 ± ·13	25·3	3·7 ± ·10
18	6·5	4·7 ± ·13	26·3	3·5 ± ·11
19	7·5	4·3 ± ·13	27·3	3·1 ± ·12
20	8·5	4·1 ± ·13	28·3	2·7 ± ·11
21	9·5	3·4 ± ·13	29·3	2·4 ± ·10
22	0·5	3·1 ± ·13	30·3	2 1 ± 09
23	1·5	2·7 ± ·11	31·3	1·5 ± ·10
24	2·5	2·2 ± ·11	32·3	1·2 ± ·09
25	3·5	1·7 ± ·10	33·3	·8 ± ·07

TABLE VIII.—COEFFICIENTS OF CORRELATION BETWEEN NEIGHBOURING FRUITING-BRANCHES.

No. of fruiting-branches.	Coefficients of correlation.		No. of fruiting-branches.	Coefficients of correlation.	
	Pruned class	Unpruned class.		Pruned class.	Unpruned class.
1–2	0·32±·082	0·47±·073	13–14	0·53±·066	0·47±·072
2–3	0·26±·085	0·44±·075	14–15	0·49±·070	0·52±·068
3–4	0·29±·084	0·45±·074	15–16	0·54±·065	0·43±·076
4–5	0·40±·077	0·42±·076	16–17	0·51±·068	0·40±·078
5–6	0·33±·082	0·33±0·83	17–18	0·60±·059	0·66±·053
6–7	0·41±·076	0·16±·091	18–19	0·63±·055	0·48±·072
7–8	0·39±·078	0·39±·079	19–20	0·57±·062	0·75±·041
8–9	0·60±·059	0·42±·077	20–21	0·41±·076	0·55±·065
9–10	0·41±·076	0·64±·055	21–22	0·62±·057	0·51±·069
10–11	0·32±·082	0·56±·064	22–23	0·55±·064	0·50±·070
11–12	0·42±·075	0·49±·071	23–24	0·54±·065	0·19±·090
12–13	0·38±·079	0·39±·079	24–25	0·41±·076	9·52±0·68

REPORT ON THE PREVALENCE OF SOME PESTS AND DISEASES OF CROPS IN THE WEST INDIES DURING 1920.

(Compiled from Reports of the Local Agricultural Officers.)

This is the twelfth report in this series. The latest previous report, that for the year 1919, appeared in the *West Indian Bulletin*, Vol. XIX, No. 1, p. 18.

The present report covers the period January to December 1920, and has been prepared in the same way as in previous years, from information supplied by the Agricultural Officers in the several islands.

ENTOMOLOGIST'S VISITS. During 1920 the Entomologist paid a lengthy visit to the Leeward Islands (January 6 to March 18). This visit was largely devoted to a study of the hard-back grub in Antigua, but a stop of a few days was made at Dominica in connexion with an outbreak of *Orthezia insignis* on limes. St. Kitts and Nevis were also visited.

The brown hard-back (*Lachnosterna antiguae*, Arrow) in Antigua, formed the subject of a paper in the *West Indian Bulletin*, Vol. XIX, p. 1.

The visit to St. Kitts and Nevis was in connexion with general entomological matters concerning the principal crops, sugar-cane and cotton.

The Entomologist attended the Official Conference of Economic Entomologists held in London, June 1 to 11.

In November the pink bollworm of cotton (*Platyedra* [Gelechia] *gossypiella*) was discovered in Montserrat and St. Kitts. The Entomologist visited these islands for the purpose of assisting the local agricultural officers in planning for the control of this pest. Antigua and Nevis were visited for the purpose of inspection, but the insect was not found there at that time.

Information with regard to the discovery of the pink bollworm in the West Indies and its subsequent spread and development as a pest of West Indian Sea Island cotton has been given from time to time in the *Agricultural News*.

MYCOLOGIST'S VISITS. Mr. W. Nowell, Mycologist on the staff of the Imperial Department, resigned his position in July 1920, to take up that of Assistant Director of Agriculture and Mycologist on the staff of the Trinidad Department of Agriculture.

Miss E. M Wakefield, of the Royal Botanic Gardens, Kew, England, was appointed Acting Mycologist from September 8, 1920, to March 27, 1921.

The Acting Mycologist visited Antigua from October 27 to November 7, and Dominica, November 9 to December 7, for

the purpose of general mycological investigations. Miss Wakefield also visited Trinidad in January 1921.

Remarks on Climate.

Amount and distribution of rainfall.

GRENADA. The rains were late in commencing, with the result that the cacao crop was late, and likely to be a short one. The weather was favourable to ground provisions and corn. Total rainfall at Richmond hill for the year was 68·66 inches.

ST. VINCENT. The rainfall for the year at the Botanic Gardens amounted to 104·83 inches. No rain fell during April. The wettest month was October, when 21·56 inches fell. The heaviest continuous downpour was on October 24 and 25, when 9·80 inches fell.

DOMINICA. The rainfall for the year was 74·56 inches. The distribution on the whole was satisfactory.

MONTSERRAT.

Rainfall for Montserrat

1920.

January	5·21
February ...	3·69
March	3·67
April	nil
May	1·12
June	2·55
July	4·89
August	6·25
September	8·00
October	4·88
November	7·39
December	7 00
Total ...	54·66 inches.

Generally speaking a prolonged drought existed in this season at the very time copious rains were required for the development and success of the staple crop, cotton. A considerable proportion of the cotton crop was established early in March, and when it is considered that the ideal rainfall, speaking generally, is that 2, 4, 6 and 8 inches of rain should fall for the four months succeeding the date of planting, the short crop produced by this island in 1920, can be understood.

ANTIGUA. The average rainfall taken from seventy stations was 30·09 inches, this being the lowest recorded since the year 1875, when an average of only 28·78 inches was obtained.

ST. KITTS. The total rainfall for the year 1920 at the Experiment Station was 38·75 inches. Of this 21 inches fell in the last five months. The drought during the first six months seriously affected the cane crop, which will be below the average.

NEVIS. The rainfall for the year from January 1 to December 31, 1920, was 38·18 inches, which is 0·01 inch less than that of last year.

Rainfall for the quarter is as follows :—

Quarter ending	March	31	7·82	inches
„ „	June	30	3·46	„
„ „	September	30	12·43	„
„ „	December	31	14·47	„

BRITISH VIRGIN ISLANDS. The rainfall for the year at the Experiment Station was 42·11 inches, as compared with 52·55 inches for the previous year. This shows a decrease of over 10 inches for the year under report. Spells of drought of great severity were experienced in March and April, and during June and July.

ABNORMAL OCCURRENCES (PERIODS OF DROUGHT, WET WEATHER, WIND)

DOMINICA. During April the weather was very dry, with a total rainfall of only 22 inches. This is the lowest rainfall recorded at the gardens for any month since the records were first kept twenty-eight years ago. Heavy squalls were experienced on the morning of November 1, and a gale of almost hurricane force blew and lasted several hours.

MONTSERRAT. It is interesting to record that in the month of April 1920, only two recording stations in the island out of a total of twenty-three stations so far as is known, measured any rain whatever, and at the two stations referred to it was quite small in amount, actually 8 and 12 parts, respectively. In spite of this remarkable drought in April, it was evident, judging from the appearance of the young cotton at the end of the month, that had ample rains fallen in the months of May and June, a normal crop would probably have been assured. As it happened, the weather, so far as rainfall is concerned, was much more nearly to the ideal for the development of the second crop, and it is practically certain that for the first time on record the second crop of cotton was larger in total amount than the first crop.

ANTIGUA. *Drought.* From the months of January to July an average amount of not exceeding 3·00 inches was recorded. From August to Novmber the heaviest rains were experienced during the month of October, when 5·41 inches were recorded.

Wind. From January to August fairly strong winds were experienced. From September to November the force of the wind was normal. The highest speed experienced during the year was 375 miles in twenty-four hours on June 22, 1920.

ST. KITTS. Period of severe drought for first seven months, fair rainfall during the latter part of year. No disturbances of any kind from wind or rain occurred during the year.

NEVIS. The early part of the year was very dry, and the dry period was worst between April and June. Toward the

latter part of the year the weather was much moister. The year, on the whole, was calm, and no damage was done to the crop from high winds.

BRITISH VIRGIN ISLANDS. One earthquake shock of slight severity was recorded on August 2. Torrential downpour of 3·80 inches recorded on May 27. High winds experienced in January and October.

INFLUENCE OF WEATHER ON CROPS.

ST. VINCENT. The heavy rainfall in October and November caused considerable damage to cotton bolls. They were heavily attacked by soft rot.

DOMINICA. The weather has been very favourable for all crops particularly limes, which have yielded a heavy crop.

MONTSERRAT. Not only had the abnormally dry period from March to July 1920 a deleterious effect on staple crops, cotton and limes, but during the whole of this period practically no vegetable crops could be planted, and much hardship resulted through the scarcity of vegetables, especially sweet potatoes, until about the month of December 1920. Fairly good crops are being reaped late in the year as the result of the satisfactory rains from July to December.

ST. KITTS. The weather has been responsible for a considerable shortage in the sugar crop, and also in the planting of ground provisions.

NEVIS. On account of the dry weather during the early part of the year great difficulty was experienced in getting the crops established, and growth was slow until September, when the rains came, from which time on the crops all made rapid progress.

BRITISH VIRGIN ISLANDS. Great difficulty was experienced in establishing cotton fields on account of the long spells of drought experienced during the planting season. Heavy rains in October and November caused some damage to cotton fields by the rotting of all bolls on the lower branches of plants.

PART 1. INSECT PESTS OF ECONOMIC PLANTS.

Sugar-Cane.

MOTH BORER (*Dialraea saccharalis*, Fabr).

GRENADA. Generally distributed. Locally severe.

ST. VINCENT. Present in all cane fields.

ST. LUCIA. Fairly general but not severe.

MONTSERRAT. Continues to be troublesome in certain localities, and is undoubtedly responsible for considerable loss on estates in the centre of the island.

ANTIGUA. Present in all cane fields throughout the island, especially in fields containing young sprouts. About 40 per cent.

of mature canes have been found to be infected with moth borer on one estate.

ST. KITTS. Generally attacking sugar-canes, but more in advanced stage. Not a large number of what is known locally as 'Dead Hearts' in young canes. The pest cannot be said to have increased.

NEVIS. The moth borer occurred throughout the island causing an appreciable amount of damage in both ratoon and plant cane fields. On nearly all the estates the cuttings are put in a lime solution, which the planters claim destroys the grubs in the cuttings, but it would appear that the death of grubs is caused from drowning rather than anything else.

BRITISH VIRGIN ISLAND. Generally present in cane fields, especially in old ratoons.

WEEVIL BORER (*Sphenophorus sericeus*, Oliv.).

GRENADA. Not reported.

ST. VINCENT. Noticed on several occasions during the season.

ST. LUCIA. Generally present but not serious.

ANTIGUA. Present in most cane fields. Not generally regarded as a very serious pest, although in fields of young sprouts, some plants have been utterly destroyed by it.

ST. KITTS. No occurrence of this pest as far as effecting any serious loss.

NEVIS. The adult was found in hedges in the neighbourhood of cane fields, but no damage is observed to have been done by the grub.

BRITISH VIRGIN ISLANDS. Not observed.

ROOT BORERS (*Diaprepes abbreviatus*, L.).

ST. LUCIA. Generally present but not serious.

MONTSERRAT. This insect is undoubtedly very rare in the island, only occasional specimens of the weevil being seen.

ANTIGUA. Not observed since 1917.

ST. KITTS. Root borers are prevalent in some districts, but there has been no special instance reported of serious loss from them.

NEVIS. Adult less prevalent than in the past; no damage observed to have been done by grub.

BRITISH VIRGIN ISLANDS. Found in ratoon canes but no great damage observed to have been done by the larvae.

Diaprepes famelicus, var. (*Exthophthalmus esuriens*).

ST. LUCIA. Found only in dead canes.

MONTSERRAT. Adult specimens are seldom seen in numbers in sugar-cane fields, but it is not known to what extent the grubs of the insect are infesting the fields.

ANTIGUA. Adults of this pest were quite common in cane fields during the month of April and May. They were observed

on the plants of the Wild Lord Lavington (*Leonurus Sibiricus* and also on Cattle tongue (*Plucheu odorata*). Larvae were also found in the soil not doing any noticeable damage.

ST. KITTS. This pest is of general occurrence, and the beetles can be found on cotton plants and in the heart of cane in large numbers. There has, however, been no actual epidemic or serious loss from them during the year. From personal observations it appears that, under good agricultural conditions, the canes are able to resist the attacks of these root borers, but where the canes are poor for want of manure, etc., they are liable to almost total destruction from these pests. In the opinion of the Agricultural Superintendent, the control of these root borers lies in bet'er agricultural conditions.

NEVIS. Exophthalmus adult observed throughout the island, on peas, cotton and lime, but no damage is observed to be done by the grub.

BRITISH VIRGIN ISLANDS. The beetles were observed in fields of young canes,

CANE FLY (*Saccharosydne saccharivora*, West.).

BRITISH VIRGIN ISLANDS. Observed in fields of canes but not apparently doing much serious damage.

WHITE ANTS OR TERMITES

ANTIGUA. Nests found in cane fields throughout the island, but very little damage appears to have been done by the insects

ST. KITTS. No report of any damage done during the year.

NEVIS. Not observed attacking the sugar-cane.

BRITISH VIRGIN ISLANDS. Generally prevalent ; not a serious pest of cane.

HARD BACK GRUBS (*Lachnosterna* spp).

ANTIGUA. *Lachnosterna antiguae* occurs chiefly in the north-eastern and central plains of the island, heavy infestations being recorded in the central plains. This insect does not occur in the southern and south-western districts. The grubs are responsible for a certain amount of damage to canes, especially in the fields of young sprouts.

Grubs of *Ligyrus tumulosus* are also to be found in fields which have been manured with pen manure. No damage to canes has been attributed to this insect.

ST. KITTS. *Ligyrus tumulosus*, both adult and grub, found in fields, especially where well manured. No damage seems to be done by them.

NEVIS *Ligyrus tumulosus*. Grub observed in rotting green manure, more around the edges of the heap than in the centre. Adult observed in the field during preparation. The insect appeared to be just about to emerge. This was

during the months of March and April. No damage has been observed to be done to the crop by this insect.

OTHER INSECTS ATTACKING SUGAR-CANE.

GRENADA. Froghopper (*Tomaspis saccharina*). Locally severe in St. Johns and St, Andrews. At a late stage in the attack, froghoppers were observed to be heavily parasitized by a fungus.

ST. LUCIA. Mealy-bug common in cane fields, especially on unmanured land. Various grasshoppers do minor damage to young cane foliage. There is also a small beetle which does a fair amount of damage to young cane.

ANTIGUA. Grasshoppers are sometimes known to eat the leaves of young canes.

ST. KITTS. Grasshoppers are a serious trouble at times to young cane plants.

NEVIS The grasshopper did a great deal of damage to the young canes. This insect is found feeding on the cane leaves all through the year, but the damage to advanced fields is not considered so bad The pest has increased during the past year. This is no doubt due to damage done to poultry by the mongoose, as both fowls and turkeys are particularly fond of the grasshoppers

Mealy-bug was observed this year throughout the island on both plants and ratoons.

BRITISH VIRGIN ISLANDS. Mealy bug common in ratoon fields, especially during the drier months.

COTTON.

COTTON WORM. (*Alabama argillacea*, Hubn.).

GRENADA. Not observed.

ST. VINCENT. A few noticed during the season. No serious infestation occurred.

ST. LUCIA. Fairly numerous but controlled by frequent applications of lime and Paris green.

MONTSERRAT. Light attacks of worms were experienced on certain areas in the month of August, but severe attackt were, as usual, comparatively late in the year, and is required persistent dusting with poison on certain areas in the months of September and October to keep them under control. It is of interest to record that very few of the peasant growers ever attempt the control of the cotton worm, and their crops are seldom severely damaged by the pest. Defoliation of the peasant s crop through attacks of cotton worm was more common than usual.

Certain localities in the island as a rule escape infestation by cotton worm, though experience in this season showed that a district that had been immune to attacks of worm for many years had a rather severe infestation in the later months of the year.

ANTIGUA. Slight attacks of cotton worms were experienced throughout the island; no considerable loss was caused from them, hence very little dusting was performed.

ST. KITTS. This pest was prevalent during the past season, and large quantities of poison were used to control it. No actual damage was done to the plants.

NEVIS. The cotton worm was very servere in its attack during the year, but ample preparations were made for dealing with the pest, and practically no damage was done by it. The attack started as early as June, when the crop was very young, and lasted (with about fourteen days between attacks), until the middle of November, when the attack ceased. The pest, for about the first time, has been kept under control.

BRITISH VIRGIN ISLANDS. Attacks were not observed until late in the year. In November and December, severe attacks were experienced, which caused great damage in the cotton fields, entirely defoliating the plants.

A. BOLL WORM (*Heliothis obsoleta*, Hubn.), and

B. CORN WORM (*Laphygma frugiperda*, S. and A.).

GRENADA. Not observed.

ST. LUCIA. Not noticed on cotton.

MONTSERRAT. A few instances of bolls damaged by this pest were observed in the month of November, but as a rule it is extremely scarce, and is not regarded as a pest of any importance at the present time.

ANTIGUA. Slight attacks of the boll worm were experienced in the southern districts of the island but not causing very considerable damage.

The corn ear worm was not observed attacking plants during the year.

ST. KITTS. These pests have been seen but in rare instances, and no damage has been done by them.

NEVIS. *Heliothis*. This pest did a great deal of damage this year, chiefly in lands cleared of bush. The planters were advised to plant rows of corn in the cotton fields, as the pest seems to prefer the corn to cotton bolls.

BRITISH VIRGIN ISLANDS The corn ear worm was noticed in small quantities in cotton fields doing practically no damage.

COTTON STAINERS (*Dysdercus* spp.).

GRENADA. Fairly plentiful on Sea Island cotton, also generally distributed on Marie Galante.

ST. VINCENT. Generally present; increased considerably towards end of season.

ST. LUCIA. Present in fair numbers on both estates on which Sea Island cotton is grown, but kept under control.

MONTSERRAT. The earliest attack on cultivated fields occurred towards the end of August, and by the middle of October

the whole of this particular estate was infested. Other scattered areas were invaded early in September, and the pest was, as usual, generally prevalent towards the end of the year,—November and December. In cases of early development of the pest, no attempt was made to control it, the infected areas being on cotton lands planted on the share system. It is to be admitted, however, that practically no attempts are made by planters to control the early attacks of this pest. Generally speaking, the loss of crop due to cotton stainers was small.

ANTIGUA. Adults of *Dysdercus andreae* appeared in large number during the months of September and October onwards. Traps of cotton seed for their control were started.

ST. KITTS. Cotton stainers appeared late in the season. They were more prevalent in northern districts where the cotton was planted early, appearing about November and December, when the cotton was nearly all reaped. The destruction of the native food-plants of this pest has been of value, and the work should be carried on.

NEVIS. This pest is not so plentiful since the campaign against it has been started. During the months of November and December (1920), when the usual attack of stainers was expected, they appeared in only certain localities, and few in number; later they appeared more generally but fewer, and damage from this pest is nil compared with past years.

BRITISH VIRGIN ISLANDS. Cotton stainers did not become noticeable before September, from which month they increased considerably.

BUSH BUGS (*Nezara viridula*, L. I., and others).

GRENADA. Generally distributed on all cotton.

ST. VINCENT. No serious attack; controlled by egg-parasites.

ST. LUCIA. Usually found in cotton patches. No damage noticed from this pest.

MONTSERRAT. This insect, as a cotton pest, is generally ignored. Observations in the Experiment Station showed that adult insects of this pest were much more plentiful early in the year, in the months of June and July, than later in the year, and this would seem to confirm the observation in St. Vincent where egg-parasitism increases towards the end of the year.

ANTIGUA. Common in all cotton fields, and also pasture lands. They are sometimes held responsible for staining cotton.

ST. KITTS. Seen in cotton fields but no damage observed.

NEVIS. Fairly plentiful this year. This pest in the past was not regarded as serious, but more damage has been done by it this year than by the cotton stainer. It occurred in nearly every cotton field, and plentifully on peas and beans and certain wild plants.

Noticed in most cotton fields.

BLACK SCALE (*Saissetia nigra*), and WHITE SCALE (*Hemichionaspis minor*).

GRENADA. Black scale not observed. White scale generally distributed ; severe.

ST. VINCENT. Present in fair quantites towards the end of the season ; did no serious harm.

ST. LUCIA. Both common on ratoon short-stapled cotton all over the island.

MONTSERRAT. Sporadic cases of attack on cotton and other groups of plants by black scale are noted but never to the extent to cause it to be regarded as a serious pest.

ANTIGUA. These were both observed, on old cotton plants but are not held responsible for any great damage,

ST. KITTS. Both the black and the white scales were observed, but plants were pulled off before any damage was done.

NEVIS. The black scale observed in many fields, but not considered a serious pest. The white scale not observed since a close season has been established. It appears to attack the crop in a later stage than the black scale.

BRITISH VIRGIN ISLANDS. Both present in cotton patches.

FLOWER-BUD MAGGOT (*Contarinia gossypii* Felt).

MONTSERRAT. Damage resulting from this insect has not been heard or seen of for many years.

ANTIGUA. Slight attacks were observed in the southern districts during the month of October.

ST. KITTS. Does not occur in St. Kitts

NEVIS. Not observed.

BRITSH VIRGIN ISLANDS. Not recorded during the year.

LEAF BLISTER-MITE (*Eriophyes gossypii* Banks).

GRENADA. Generally distributed and fairly scarce on Marie Galante cotton in Carriacou, Grenada and Isle de Rhonde.

ST. VINCENT. Present on secondary growth at the end of the season ; caused no injury to crop.

ST. LUCIA. Persistent efforts to destroy this pest in Sea Island cotton trial fields keep it under control. Otherwise found in cotton bush all through the island.

MONTSERRAT. This pest was generally more prominent than for many years, in spite of the fact that the destruction of the old cotton crop early in 1920 was very efficiently performed. It was frequently suggested during the season, that the striking prominence of the pest was in some way associated with the particularly dry season in the early period of growth, and some importance must be attached to this circumstance

ANTIGUA. Common throughout the island. Owing to the large amount of wild cotton plants growing in uncultivated lands, the control of this mite was made very difficult.

ST. KITTS. Leaf blister-mite was very prevalent at the close of the season, but little damage was done to cotton plants. It was hoped that the close season for cotton would have almost eradicated this pest, but this has not been the case.

NEVIS. Not so plentiful as in the past. This is due to the establishment of a close season.

BRITISH VIRGIN ISLANDS. Found wherever cotton is grown, and is a serious menace to late planting. Early planted fields are less susceptible to infestation

OTHER INSECTS ATTACKING COTTON.

ST. VINCENT. Red spider on cotton at the Experiment Station. Aphis is somewhat abundant in the windward district.

MONTSERRAT. On November 5, 1920, the pink bollworm of cotton (*Gelechia gossypiella*) was discovered in the island in considerable numbers on the area where it was found. The early observations indicated that the pest was confined to the neighbourhood of the port (Plymouth), but at the close of November and in December it was found to be distributed from the town to the extreme north of the island, only slightly towards the south, and to some extent towards the eastern or windward side of the island the latter district being relative free from it.

ANTIGUA. The red lady-bird beetle (*Cycloneda sanguinea*) was observed to be very common in cotton fields. Larvae of the lesser cotton worm (*Alctia luridula*) were found in cotton bolls, but are not held responsible for doing any great damage.

ST. KITTS. The pink bollworm of cotton (*Gelechia gossypiella*) was discovered in St. Kitts on November 15, at La Guérite Experiment Station, and later on the estates from the town of Basseterre to Cranstouns estate. Cockroaches have been observed cutting off the young plants soon after germination.

NEVIS. Lachnopus observed doing a fair amount of damage on a certain estate. A large black grass worm did a fair amount of damage to young cotton by feeding heartily on the leaves.

BRITISH VIRGIN ISLANDS. Cotton aphis was particularly prevalent during the dry months.

CACAO.

THRIPS (*Heliothrips rubrocinctus Giard*).

GRENADA. Generally distributed, and in some instances locally severe. Spraying with Bordeaux mixture and soap-nicotine has been carried out on several estates with success. Generally speaking, records show that this has been the mildest year for thrips since 1916. Spraying demostrations have been given to the peasants.

ST. VINCENT. No serious attacks.

ST. LUCIA. Severe, generally on lowlands and damp hillsides.

DOMINICA. Generally present in cacao cultivation. No bad effects reported.

BEETLE (*Steirastoma depressum, L.*).

GRENADA. Observed principally on the western side of the Island.

ACROBAT ANT (*Cremastogaster brevispinosa*, Forel.).

GRENADA. Generally distributed and locally severe.

SCALE INSECTS AND MEALY-BUGS.

GRENADA. Generally distributed on cacao in close association with the Acrobat ant.

ST. LUCIA. Mealy-bugs often found on flower cushions, pods and leaves.

BRITISH VIRGIN ISLANDS Mealy-bugs occasionally met with in the few isolated cacao patches in the island.

OTHER INSECTS ATTACKING CACAO.

GRENADA. Termites (*Kalotermes balloui*) observed on the eastern side of the island. Locally severe. Further investigations regarding this pest are being made.

LIMES AND OTHER CITRUS.

SCALE INSECTS.

GRENADA. The following are generally distributed and are locally severe: *Lepidosaphes beckii, Chionaspis citri, Coccus viridis, Selenaspidus articulatus.*

ST. VINCENT. Citrus plants generally badly attacked.

ST. LUCIA. *Chionaspis citri* generally present, especially in dry and exposed situations. *Saissetia nigra* found in fields where okros have been grown. *Coccus viridis* generally present, severe in nursries. *Selenaspidus articulatus* generally present on lime leaves, apparently doing little damage. *Lepidosaphes beckii* generally distributed; severe, more especially where cultivation is poor.

DOMINICA. A severe attack of *Orthezia insignis* on lime trees occurred on the south side of the island towards the close of 1919, and continued more or less senere during 1920. The pest was also found on an estate on the leeward coast, and to some extent in the Lime Experiment Station. The pest is now confined to ths Soufrière district.

MONTSERRAT. There have been no striking epidemics of scale insects during the year, except that on restricted areas, the long drought from March to July 1920 resulted in considerable development of purple scale, with the accompanying dying back branches,

The green scale and Croton bug have been comparatively scarce for some years, consequently the trees have not been severely infested with black blight.

ANTIGUA. The following scale insects were observed: The purple scale (*Lepidosaphes beckii*), the Orange snow scale (*Chionaspis citri*), and the green scale (*Coccus viridis*,).

ST. KITTS. No lime cultivation to any extent in St. Kitts, but scale insects are found on all trees.

BRITISH VIRGIN ISLANDS. *Chionaspis citri* generally present, especially during spells of dry weather. Others found are *Lecanium hemisphericum*, *Saissetia nigra*, and *Coccus viridis*.

BARK BORER (*Leptostylus praemorsus*).

GRENADA. Not reported.

ST. LUCIA. Present in the drier districts, not severe, controlled.

DOMINICA. Occasionally met with.

ANTIGUA. Adults have been found in the southern parts of the islands. This pest is apparently on the increase.

TWIG BORER (*Elaphidion mite*).

No records of the occurrence of this pest during the year.

ROOT BORERS, ROOT GRUBS (*Diaprepes* spp.) and (*Exophthalmus* spp.).

ST. LUCIA. *Diaprepes abbreviatus*, var is fairly numerous, but damage to roots uncertain.

ANTIGUA. No observations made.

BRITISH VIRGIN ISLANDS. The larvae of (*Diaprepes abbreviatus var. spengleri*) common in lime fields. The adults noticed flying about and eating lime leaves.

OTHER INSECTS ATTACKING CITRUS.

ST. LUCIA. Weevil (*Neocyphus pudens*) found attacking lime in the Soufriére district.

SWEET POTATO.

SCARABEE (*Cryptorhynchus batatae*, Waterhouse).

ST. VINCENT. Found in overripe potatoes. No serious attack occurred.

ANTIGUA. Common on all peasant lands, especially where sweet potatoes are continually being grown. In some districts the entire crop is lost. Sweet potatoes grown in rotation are usually free from infection.

ST. KITTS Found in poor land but not in great abundance.

NEVIS In very few places was this pest observed, and its occurence is due chiefly to the crop being allowed to remain in the ground too long.

BRITISH VIRGIN ISLANDS. This insect is only noticed in over-ripe fields and is not considered a very serious pest at present.

CATERPILLARS (*Protoparce cingulata*, Fabr.) and others.

ST. LUCIA. Caterpillar attacks were serious during November and December.

ANTIGUA. Common throughout the island, and fields have been observed to have been entirely defoliated through this pest.

ST. KITTS. No record this year.

NEVIS. Protoparce observed in only a few places. Not considered a serious pest.

BRITISH VIRGIN ISLANDS. Very servere attack experienced, and much damage done to the crop during the month of October.

THRIPS.

ST. LUCIA. Present, not severe.

RED SPIDER (*Tetranychus telarius*, Linn.).

ST. VIVCENT. Found during the season. No serious attack occurred.

OTHER INSECTS ATTACKING SWEET POTATO.

ST. LUCIA. The common slug (*Veronicella occidentalis*) is a real pest in low wet lands, principally. Bush bugs generally distributed, but damage not severe.

DOMINICA. The 'Palute' (*Veronicella occidentalis*) eats the leaves of sweet potatoes. Always present to some extent.

GROUND NUTS.

GREEN BUG (*Edessa meditabunda*, F.) and others.

ST. VINCENT. Generally present.

MEALY BUG.

NEVIS. Observed in plot at Experiment Station, but not to a great extent.

BRITISH VIRGIN ISLANDS. Generally present.

LEAF-EATING CATERPILLARS.

ST. LUCIA. Generally present.

OTHER INSECTS ATTACKING GROUND NUTS.

No records during the year.

COCO-NUTS.

WEEVIL (*Rhyncophorous palmarum*, Linn.).

GRENADA. Observed in trees dying or dead from Red Ring disease, also destroying hearts of young coco-nut palms. Generally distributed, and noticed to be locally severe in one instance.

ST. VINCENT. Few instances noticed during the year.

ST. LUCIA. Rarely met with.

WHITE FLY (*Aleyrodicus cocois*, Curtis).

ST. VINCENT. Fairly common.

ST. LUCIA. Present, generally not serious.

DOMINICA. Occasionally found on young coco-nuts.

BRITISH VIRGIN ISLANDS. Noticed, but no serious damage done to trees.

SCALE INSECTS (*Aspidiotus destructor*, Sign.), and others.

GRENADA. Generally severe, more so during the dry season.

ST. VINCENT. Generally present.

ST. LUCIA. Fairly serious and general on young trees in dry situations, during dry spells, and in sandy soil along the coast. *Diaspis boisduvalii* also present in situations similar to those mentioned above, and fairly serious.

DOMINICA. Scale insects are occasionally met with on coco-nut palms throughout the island. The serious attack of *Aspidiotus destructor* reported from the Windward Coast last year is now under control.

ANTIGUA. Generally observed on the under surface of the leaves throughout the island, but apparently does little damage.

ST. KITTS. No large coco-nut cultivation in St. Kitts, but scale insects are found on all trees.

NEVIS. Aspidiotus observed throughout the island, but chiefly on the older leaves, and on younger leaves on plants growing under bad conditions. Also observed on bunches of nuts at Pinneys and other places.

BRITISH VIRGIN ISLANDS. Prevalent in all coco-nut-growing districts.

INDIAN CORN.

CORN EAR WORM (*Heliothis obsoleta*, Hubn.) and (*Laphygma frugiperda*, S. and A.).

GRENADA. Noticed in various localities in form of mild attacks.

ST. VINCENT. Generally present. Did no serious damage.

ST. LUCIA. Generally distributed. Particularly troublesome throughout the year all over the island.

ANTIGUA. Usually found in corn fields.

ST. KITTS. Very prevalent, and did much damage to young corn.

NEVIS. Very abundant throughout the island, causing a fair amount of damage.

BRITISH VIRGIN ISLANDS. Corn ear worm is generally present in corn fields.

HARD BACK GRUBS (*Lachnosterna* spp.)

ANTIGUA. Grubs of *Lachnosterna antiguae* are plentiful in some districts, often causing considerable damage.

ST KITTS. Not observed damaging corn.

NEVIS. Not observed attacking corn.

BRITISH VIRGIN ISLANDS. Grubs of *Lachnosterna* spp. noticed.

OTHER INSECTS ATTACKING INDIAN CORN.

ST. VINCENT. *Diatraea saccharalis* generally present.

ST. LUCIA. Grain weevils generally distributed. Attack both in the fields and in store.

MONTSERRAT. It is possible that the very young caterpillars of the worm *Prodenia* sp. can destroy young germinating corn. A plot of special corn from Bermuda was planted in the Experiment Station in September, and as the seedlings germinated, at less than four days from planting, they were found to be plentifully infested with small caterpillars, and were completely destroyed even before they had formed a stand. The habits of the corn ear worm would probably not account for the infestation by this pest at so early a stage.

ANTIGUA. Adults of *Tachytes argentipes* were observed on corn plants, apparently attracted by the inflorescence. Adults of *Tiphia parallela* were also found on corn plants during the year. The granary weevil is common when seed is stored.

ONIONS.

CATERPILLARS.

ANTIGUA. Common in onion fields. Collecting by hand for its control is adopted, and found to be the best method of control.

NEVIS. Observed in nursery beds but did no damage to general crop.

BRITISH VIRGIN ISLANDS. Onions in all districts suffered from attacks of caterpillars.

THRIPS (*Thrips tabaci*, Lind.).

ANTIGUA. Observed in fields during the year but apparently not on the increase.

BRITISH VIRGIN ISLANDS. Common in onion fields.

OTHER INSECTS ATTACKING ONIONS.

ANTIGUA. Grubs of *Lachnosterna antiguae* have been found in Antigua onion fields apparently attacking the roots of the plants, but no great damage has been recorded.

YAMS.

SCALE INSECTS (*Aspidiotus hartii*.).

GRENADA. Yams were observed to be attacked severely in two parishes. Specimens were forwarded to the Imperial Commissioner of Agriculture.

ST. VINCENT. Fairly common.

ST. LUCIA. Generally distributed, fairly serious.

ANTIGUA. Usually found, but apparently does very little damage.

ST. KITTS. Attacks stored yams.

OTHER INSECTS ATTACKING YAMS.

ST. LUCIA. Slugs are troublesome during early growth.

ANTIGUA. Grubs of *Lachnosterna antiguae* have been found in a field of yams, but apparently very little damage was done by them.

Green Dressings—Beans and Peas.

LEAF-EATING CATERPILLARS.

GRENADA. Severe attacks of *Anticarsia gemmatalis* were observed on *Canavalia ensiformis.*

MONTSERRAT. Were not prominent on green dressing crops during the year.

ANTIGUA. Green dressings of white velvet bean, and the fleshy pod bean have been attacked, often causing complete defoliation.

ST. KITTS. These were prevalent on all kinds of green dressings, owing chiefly to the very dry season.

BRITISH VIRGIN ISLANDS. Caterpillars were noticed attacking *Canavalia ensiformis,* pigeon peas, and black-eye peas, but no great damage was done.

BUSH BUGS (*Nezara viridula*).

ST. VINCENT. Generally present.

ANTIGUA. These were observed to be very common, but are not held responsible for doing much damage.

NEVIS. Nezara very abundant on peas and beans, causing a great deal of damage by sucking the pods.

BRITISH VIRGIN ISLANDS. Noticed in fields of black-eye peas and pigeon peas

OTHER INSECTS ATTACKING THESE CROPS.

ST. VINCENT. *Ballovia* sp. found attacking pods of pigeon peas and cowpeas.

ST. KITTS. Grasshoppers at times cut off the young plants.

Plantains and Bananas.

BLACK WEEVIL BORER (*Cosmopolites sordidus.*)

ST. LUCIA. Generally distributed and on the increase. Damage is more apparent during the dry season. The spread of

this insect is materially aided by neglect in examining suckers carefully, before planting new gardens.

DOMINICA. Present, but no serious damage reported.

WEEVIL BORER (*Metamasius sericeus*, Oliv.).

No records during the year.

LARGE BLACK HARD BACK BORER (*Tomarus bituberculatus*, Beaud.).

ST LUCIA. Generally distributed and serious, particularly during spring and the beginning of the wet season. This pest, besides being able to fly fairly long distances after nightfall, is spread in very much the same way as the black weevil borer.

TANNIAS, DASHEENS, EDDOES.

BANANA BORER (*Tomarus bituberculatus*, Beaud.)

ST. LUCIA. Generally distributed and serious, particularly during spring and the beginning of the wet sea-son. Retards the growth and development of the plant, and sometimes destroys it completely.

LACEWING BUG.

ST. LUCIA. Generally distributed, not serious.

GENERAL REMARKS.

MISCELLANEOUS INSECTS NOT OTHERWISE PROVIDED FOR.

GRENADA. An unidentified beetle, attacking pine-apples, specimens of which were forwarded to the Imperial Commissioner of Agriculture, was observed as a serious pest in one locality. Loss of the crown of the pine was the injury, also puncturing and gumming of the fruit.

ST. VINCENT. Mole cricket, a common pest of garden vegetables also attacks Indian corn and cotton.

ST. LUCIA. The mole cricket (*Gryllotalpa didactyla*) is a common pest of garden vegetable crops, especially cabbage, lettuce, tomatoes, etc, and is difficult to control. Lawns also suffer materially from the ravages of this insect.

ANTIGUA. The larvae and adults of *Mallodon maxillosum* were found in the interior of Sandbox tree. (*Hura crepitans*), several trees dying in consequence. Adults of *Phileurus valgus* were also found.

ST. KITTS. A large borer does great damage to White Cedar trees throughout the island.

NEVIS. The grasshopper has been a source of damage to young canes. Lachnopus for the past three or four years has appeared as a pest of cotton.

BRITISH VIRGIN ISLANDS. *Calpodes ethlius* attacks canna. *Batocera rubus* attacks papaw and wild fig.

NATURAL ENEMIES OF INJURIOUS INSECTS—PARASITIC AND PREDACEOUS INSECTS.

GRENADA. Lady bird beetles were generally distributed.

ST. LUCIA. Jack Spaniards are fairly well distributed in the Soufrière district.

ANTIGUA. Soil grubs of *Lachnosterna antiguae* were observed to be parasitized by *Tiphia parallela*.

The wild bee or Jack Spaniard was observed in the northern and southern districts of the island.

Adults of *Campsomeris dorsata*, *Tachytes argentipes*, and *Sphecidae* were observed in the island during the year.

ST. KITTS. Jack Spaniards help in keeping the cotton worm in check.

NEVIS. Chalcis as a parasite of the cotton worm was observed during the month of November.

The fiery ground beetle was observed feeding on the cotton worm in the New Road district.

The Jack Spaniard was fairly plentiful in all the cotton fields. They appear to leave the dry districts during the hot seasons, and the remaining few become less aggressive.

BRITISH VIRGIN ISLANDS. Jack Spaniards are becoming more common in the Virgin Islands again. In Tortola, quite a few nests have appeared.

OTHER REMARKS.

ST. KITTS. Insects generally have been prevalent during the year, the results of the very dry weather.

NEVIS The cotton worm was severe in its attacks this season but it was kept in check by the use of insecticides. There is a marked reduction in the number of cotton stainers, and the damage done to the crop by this pest is becoming less and less. Nezara, however, seems to be on the increase.

On the whole, the damage done to crops this year has not been great.

BRITISH VIRGIN ISLANDS. Insect pests, on the whole, were only serious during the last three months of 1920, especially in November. Curly leaf disease of cotton was noticed during the wet months in Tortola.

PART II.—DISEASES OF ECONOMIC PLANTS.

CACAO.

ROOT DISEASES (*Rosellinia* spp.)

GRENADA. Local attacks have been observed. Copperas has been used as a control.

ST. LUCIA. Well distributed and severe in many plantations in the Soufrière district. Control measures are persistent in all diseased plantations.

CANKER. (*Phytophthora Faberi*, Maub.).

GRENADA. Generally distributed and, in some instances, locally severe. Kept largely under control by tree surgery and the application of antiseptics.

ST. LUCIA. generally severe and distributed throughout the island. Improved methods of cultivation keep it under control on the larger plantations.

DOMINICA. Fairly common throughout the island at all times. A few severe cases noticed on estates on the Leeward Coast.

BLACK ROT OF PODS (*Phytophthora Faberi*, Maub.).

GRENADA. Not reported.

ST. LUCIA. Met with in plantations generally during heavy wet season. Was not so apparent this year. Control measures are undertaken in the larger plantations, and are being gradually adopted among the peasantry.

DOMINICA. Always present particularly on delicate varieties of cacao suffering from canker.

BROWN ROT OF PODS *Diplodia Theobromae*, Pat.).

GRENADA. Generally distributed and locally severe. Bordeaux nicotine used for spraying thrips serves to control this disease as well.

ST. LUCIA Present generally ; not serious this season.

DOMINICA. No serious cases reported or observed.

DIE BACK AND STEM DISEASE (*Diplodia Theobromae*).

GRENADA. Local, not severe.

ST. LUCIA. Generally bad, more serious on exposed situations

DOMINICA. Cacao fields are rarely found entirely free from this disease. Most troublesome on wind-swept land.

PINK DISEASE (*Corticium salmonicolor*, B and Br.).

GRENADA. Not reported.

THREAD BLIGHTS (*Corticium*, sp., etc.).

GRENADA. Not reported.

ST. LUCIA. Present in small plantations adjoining heavy forests

HORSE HAIR BLIGHT (*Marasmius equicrinus*, Mull, Blanc).

GRENADA. Observed in the highlands. Not observed.

COCO-NUTS.

BUD ROT (*Phytophthora palmivora*. Butl, etc.),

GRENADA, Not reported.

ST. LUCIA. Distributed to a limited extent. Few cases were reported during the year.

NEVIS. Occurred sporadically during the year in one plantation.

BRITISH VIRGIN ISLANDS. Not noticed,

RED RING DISEASE (*Aphelenchus cocophilus*, Cobb).

GRENADA. Generally distributed and locally severe. prevention methods are in many instances being adopted to check its spread. Successful experiments were carried out at Westerhall for the destruction of diseased trees in the same form as charcoal is burnt.

ST. LUCIA. No cases reported as yet.

LEAF BLIGHT (*Pestalozzia palmarum*, Cke.).

GRENADA. Not reported.

ST. LUCIA. Present, not serious.

INDIAN CORN (see *Agric. News* XIV, 78).

RUSTS Red or Brown, (*Puccinia sorghi*, Schw.) (*P. maydis*, Bereng).

GRENADA. Not reported.

ST. VINCENT. Present, causing no serious injury.

ST. LUCIA. Brown rust is fairly common.

ANTIGUA. Generally found in maize fields.

ST. KITTS. Nil.

NEVIS. Occurred generally throughout the island, but chiefly on old plants.

BRITISH VIRGIN ISLANDS. Fairly common but not a serious disease.

SMUT (*Ustilago Zeae*, (Beckm.) Ung).

GRENADA. Observed, not severe.

ST. VINCENT. Generally fairly common.

ANTIGUA. A few cases observed during the year.

ST. KITTS. Instances are observed but not to a great extent.

NEVIS. Occurred in a few places but not to a great extent.

BRITISH VIRGIN ISLANDS Not serious.

ROOT DISEASE.

ANTIGUA. Slight infestations found when grown with cane.

ST KITTS. Not observed.

NEVIS. Not observed.

BRITISH VIRGIN ISLANDS Isolated instances observed.

IMPHEE AND GUINEA CORN.

RUSTS (*Puccinia purpurea*, Cke.).

NEVIS. Of general occurrence when crop is ripening.

SMUT. *Agric. News*, XIII, 316 (*Sphacelotheca sorghi*, I. K. Clinton).

GRENADA. Not reported,

NEVIS Not observed.

ROOT DISEASE.

GRENADA. Not reported,

Cotton.

SOFT ROT OF BOLLS (*Phytophthora sp.*).

GRENADA. Not reported.

ST. VINCENT. Common in October and November; caused a fair amount of damage.

MONTSERRAT. Found to be fairly plentiful in the showery month of September 1920, and is always responsible for the loss of a proportion of bolls in showery damp weather.

ST KITTS. Observed at the end of the season during wet weather

NEVIS, Not observed,

WEST INDIAN LEAF MILDEW (*Ovulariopsis gossypii*, Wakf.).

GRENADA. Not reported.

ST. VINCENT. Common at the end of the season.

ST. LUCIA. Prevalent during the wet November month.

MONTSERRAT. This was particulary evident on the heavier soils of the island during the third and fourth months of the crops' development (May and June), and it appeared in some way to be generally associated with the disease known as rust. In no previous season had there been such an amount of defoliation resulting from a combination of these troubles, but this was not evident on the lighter sandy soils of the island. The response to the rains in the later part of the year was very much less evident on the areas that had been partly defoliated in this way, on the first growth.

ANTIGUA. Generally found on plants towards the end of the crop.

ST. KITTS. Appeared at the end of the cotton season but did no damage.

NEVIS. Of general occurrence throughout the island. Not considered serious, as it generally occurs in fields that are ripening, and towards the end of the season.

BRITISH VIRGIN ISLANDS Present.

BACTERIAL BOLL DISEASE (external) (*Bacterium malvacearum*, E. F. S.)

ST. KITTS. Not observed.

NEVIS. Of more general occurrence than in the past.

BRITISH VIRGIN ISLANDS. Of rare occurrence during the season.

ANGULAR LEAF SPOT (*Bacterium malvacearum*).

GRENADA. Not reported.

ST. VINCENT. Generally present.

ST. LUCIA. Present to a limited extent.

MONTSERRAT. Our type of cotton is fairly immune to the disease associated with *Bacterium malvacearum*.

ST. KITTS. Observed to a slight extent, but not dangerous.

NEVIS. Of general occurrence throughout the island in fields that are ripening.

INTERNAL BOLL DISEASE (*Nematospora coryli*, Pegl., *Nematospora* sp., *Eremothecium cymbalariae*, Borzi, etc.).

GRENADA. Not reported.

ST. VINCENT. Common towards the end of the season.

MONTSERRAT. As usual associated with the attacks of green bug and cotton stainers.

ANTIUGA. Found throughout the island.

ST. KITTS. There has not been much loss from internal boll disease, as the loss from pink bollworm has taken its place.

NEVIS. Not so plentiful as in the past, but still occurst o a fairly great extent.

BRITISH VIRGIN ISLANDS. Generally distributed and did serious damage in wet months.

OTHER DISEASE OF COTTON OR GENERAL REMARKS.

ST. KITTS. The cotton crop has suffered early from lack of rain. The later planted fields would have yielded well, but the presence of pink bollworm will lesson the return.

NEVIS. A fair number of 'chilled' bolls was observed during the damp season

BRITISH VIRGIN ISLANDS. Owing to lack of proper cultural treatment many cotton fields yielded poorly. Heavy rains in October and November caused the decaying of the majority of bolls on lower branches of cotton plants.

Ground Nuts.

ROOT DISEASE (*Sclerotium Rolfsii*, Sacc.).

GRENADA. Not reported.

NEVIS. Not observed.

LEAF RUST (*Uredo arachidis*, Lag.).

GRENADA. Not reported.

ST. VINCENT. Generally present.

ST. LUCIA. Generally distributed, especially on wet lands.

ST. KITTS. Nil.

NEVIS. Occurred in the plot at the Experiment Station, but not to any great extent.

Limes and other Citrus Plants.

BLACK ROOT DISEASE (*Rosellinia* spp.).

GRENADA. Not reported.

ST. LUCIA. Appears on limes supplied to vacancies in cacao plantations caused by same disease in cacao.

DOMINICA. *Rosellinia bunodes* is fairly common on lime trees in newly cleared forest lands *Rosellinia pepo* has been found

on one estate only. Both diseases can be controlled by burning diseased trees, and isolating contacts.

RED ROOT DISEASE (*Sphaerostilbe* sp.).

GRENADA. Not reported.

DOMINICA. Trees suffering from Red root disease (*Sphaerostilbe* sp.) were observed on two adjoining estates on the Leeward Coast during the year. Red root disease in Dominica appears to be confined to these two estates.

UNIDENTIFIED ROOT OR COLLAR DISEASES.

GRENADA. Generally distributed and locally severe.

DOMINICA. Collar rot on lime trees has been giving a good deal of trouble during the year. The disease can be treated in the early stages with good results by painting the diseased parts with lime and sulphur solution. Collar rot on orange trees was noticed on one estate only.

DIE-BACK

GRENADA. Generally found on trees infested with scale insects. Generally severe.

ST. LUCIA. Noticeable on low badly drained heavy lands.

DOMINICA. Commonly met with on estates where limes are grown on shallow or wind-swept land. Lack of sufficient humus in the soil and bad drainage contribute to the cause.

SEEDLING DISEASES.

GRENADA. 'Damping off' observed at the Botanic Station.

ST. LUCIA. 'Damping off' disease very prevalent during wet season in damp situations.

DOMINICA 'Damping off' of seedling lime trees is easily controlled by dusting the leaves, on the first appearance of the disease, with equal parts of lime and sulphur.

MONTSERRAT. Lime seedlings are invariably attacked by the mildew described in the Annual Report on the Montserrat Botanic Station for 1918-19, but Bordeaux mixture is found to be an effective remedy or preventive.

OTHER DISEASES OF LIME OR GENERAL REMARKS.

ANTIGUA. The lime cultivations in certain districts of the island have decidedly improved during the year under review, attention being especially given to the manuring of trees with pen manure and the cutting of all deadwood. Plants of Gliricidia were planted in the effort to established wind-breaks, but unfortunately, owing to drought, very few plants established themselves.

SUGAR-CANE.

ROOT DISEASE (*Marasmius Sacchari*. Wakker) and allied species.

GRENADA Not reported.

ST. VINCENT. Fairly common

ST. LUCIA Generally severe, particularly in the Bourbon variety.

ANTIGUA. Common throughout the island, especially in ratoon cane fields, and fields badly drained.

ST. KITTS. This disease is fairly prevalent throughout the island but only does damage where bad agricultural conditions are present.

NEVIS. Occurred throughout the island but not to any great extent.

BRITISH VIRGIN ISLANDS. Not generally present throughout the Presidency.

RIND FUNGUS (*Melanconium Sacchari*, Massee.).

GRENADA. Not reported.

ST. VINCENT. Common on over-ripe canes.

ST. LUCIA. General, particulary on wet lands.

ANTIGUA. Found throughout the island.

ST. KITTS. Not observed.

NEVIS. Observed in a few fields during reaping time.

RED ROT DISEASE (*Colletotrichum falcatum*, Went.).

GRENADA. Not reported.

ST. KITTS. Not observed.

NEVIS. Not observed.

PINE-APPLE DISEASE (*Thielaviopsis paradoxa*, von Hohn.).

GRENADA. Not reported.

ST. VINCENT. Noticed on cane cuttings.

ST. LUCIA. Present, not serious.

ANTIGUA. A few observed.

ST. KITTS. Not observed.

NEVIS. Not observed.

OTHER DISEASES OF SUGAR-CANE, OR GENERAL REMARKS.

ST. KITTS. There has been no epidemic of sugar-cane diseases during the year, and the recovery of the canes after the drought proved that they were in a healthy condition.

NEVIS. The cane crop on the whole, suffered from no serious fungoid diseases during the year.

SWEET POTATOES.

WHITE RUST (*Albugo* (*Cystopus*) *ipomeae panduranae* (Schw.) Sw.)

GRENADA. Not reported.

NEVIS. Not observed.

OTHER DISEASES, OR GENERAL REMRAKS.

NEVIS. This crop has been particularly healthy during the year.

BRITISH VIRGIN ISLANDS. A form of root disease observed in fields of English potatoes, and did some amount of damage to crop.

Bananas and Plantains.

Marasmius rot (*Marasmius stenophyllus*, Mont. *semiustus*, Mass.)

GRENADA. Not reported.

ST. LUCIA. Generally distributed and severe.

DOMINICA. Not known.

Yams.

Tuber diseases.

GRENADA. Not reported.

ANTIGUA. Not observed.

ST KITTS. Not observed.

NEVIS. Not observed

Wilt diseases.

GRENADA. Reported in association with *Aspidiotus Hartii*.

ANTIGUA. Not observed.

ST. KITTS. Nil.

NEVIS. Not observed.

Onions.

Bacterial rot.

GRENADA. Not reported.

DOMINICA Present, but not causing any damage.

ANTIGUA. Very little of this disease observed during the year.

ST. KITTS. Not observed.

NEVIS. Not observed.

BRITISH VIRGIN ISLANDS. Present in Virgin Islands.

Fungi Parasitic on Insects.

On scale insects.

GRENADA. *Cephalosporium lecanii* generally distributed.

BRITISH VIRGIN ISLANDS. Red-headed and shield-scale fungus seen during the year.

ST. LUCIA. The four common species occurred as usual.

DOMINICA. Fungus parasites, particularly the red-headed fungus (*Sphaerostilbe coccophila*), continue to do excellent work, in controlling attacks of scale insects.

ANTIGUA None observed.

ST. KITTS. None observed.

BRITISH VIRGIN ISLANDS. Red-headed fungus fairly common.

On any other insect.

GRENADA. Not reported.

ST. KITTS. None observed.

NEVIS. Not observed.

Phanerogamic Parasites.

LOVE VINE (*Cuscuta* sp).

GRENADA Generally distributed and locally severe. Shows tendency to increase.

ST. VINCENT. Common on bushes and estate land.

ST. LUCIA. Locally severe on wild as well as cultivated plants. Attempts to destroy it are generally made with more or less success. Among cultivated plants, hedges suffer most.

DOMINICA. Not plentiful.

MONTSERRAT. There are periods when the love vine is very prominent, but it appears to be attacked by a fungus or some controlling agent that turns it a brown colour, and it eventually dies.

ANTIGUA. A few cases observed in the island.

ST. KITTS. This pest is increasing on wild plants in villages, but does not attack cultivated plants.

NEVIS. Has increased especially on hedges.

BRITISH VIRGIN ISLANDS Continues to increase, and is destructive to hedges. Is also known to attack cotton, pigeon peas, cassava, and many wild plants.

MISTLETOE (*Dendropemon* sp.).

GRENADA. Generally distributed and locally severe on cacao.

ST. LUCIA. Generally troublesome on limes and cacao, but receiving attention generally.

DOMINICA. Very common on cacao trees in one district, Occasionally met with elsewhere in the island, but not to any great extent.

ST. KITTS. Not observed.

NEVIS. Generally observed.

BRITISH VIRGIN ISLANDS. Common on pear trees.

REMARKS ON ANY OTHER PLANT DISEASES.

ST. VINCENT. Imported tomato varieties generally affected by wilt diseases (*Bacterim solanaecarum*, E. F. S.

ST. LUCIA. Rosellinia root disease was locally present on avocado pear.

DOMINICA. Two diseases found on the leaves of French beans (*Phaseolus vulgaris*) were identified as Rust (*Uromyces appendiculatus* Lnk.) and leaf spot (*Cercospora cruenta* Sacc) A Fungus (*Mycophaerella brassicaecola*) together with a bacterial rot did considerable damage to cabbages planted on a fairly large scale on one estate in a wet district.

ST. KITTS. What is known locally as 'Old man's beard' *Tillandsia* sp.) is a great pest on certain trees, and is widely distributed.

NEVIS. None.

SUMMARY OF DISTRIBUTION.

The following table is intended to show the status and distribution of the pests and diseases affecting West Indian crops during 1920. It has been prepared from the reports which have been used in the compilation of the notes given in the preceding pages The following letters and signs are used as indicated, for brevity and graphic representation.

g = generally distributed.
G = generally distributed, severe.
l = local.
L = locally severe.
gL = generally present, locally severe.
r = occurred during year.
? = of doubtful occurrence.
– = not known to occur in the island.
o = no record during the year.
Blank space. Crop not grown in island, or of no importance.

INSECT PESTS.

	Grenada.	St. Vincent.	St. Lucia.	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Virgin Islands.
Bananas and Plantains.									
Black Weevil Borer	o	o	G	r					
Brown Weevil Borer	o	o	o	o					
Black Hard-back Borer	o	o	G	o					
Other Insects	o	o	o	o					
Cacao.									
Thrips	gL	o	G	g					
Beetle	l	o	o	–					
Acrobat Ant	gL	o	o	o					
Mealy-Bugs	g	o	r	o					
Termites	L	o	o	o					
Coco-nuts.									
Weevil	g	r	?	–		–		–	–
White Fly	o	r	g	r		o		o	r
Scale Insects	G	g	g	r		r	r	r	r
Other Insects	o	o	o	o				o	o
Corn (Indian).									
Corn Ear Worm and Boll Worm	r	g	G		o	g	o	G	g
Hard Back Grubs	o	o	o		o	L	o	o	r
Grain Weevils	o	o	g		o	r	o	o	o
Moth Borer of Sugar-cane ...		g	o		o		o	o	o
Cotton.									
Cotton Worm	o	r	g		g	g	G	G	G
Lesser Cotton Worm	o	o	o		o	r	o		o
Boll Worm and Corn Ear Worm	o	o	o		r	l	r	L	r
Pink Bollworm	–	–	–		l	–	l	–	–
Cotton Stainers	g	g	g		g	G	l	g	g
Bush Bugs	g	r	r		g	g	r	g	g
Scale Insects	G	r	g	l	l	r	r	r	r
Flower-bud Maggot	–	–	–		o	r	o	o	o
Leaf-Blister Mite	g	r	g		g	g	g	r	g
Aphis	o	l	o		o	o	o	o	g
Red Spider	o	l	o		o	o	o	o	o
Cockroaches	o	o	o		o	o	l	o	o
Lachnopus	o	o	o		o	o	o	l	o
Caterpillar	o	o	o		o	o	o	l	o

INSECT PESTS.—(*Continued.*)

	Grenada.	St. Vincent.	St. Lucia.	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Virgin Islands.
GREEN DRESSINGS.									
(Beans and Peas.)									
Leaf-eating Caterpillars ...	L	o				L	gg	o	gg
Bush Bugs	o	gg				gg	o	gg	r
Grasshoppers	o	o				o	o	o	o
Ballovia	o	r				o	o	o	o
GROUND NUTS.									
Bush Bugs		gg	o				o	o	o
Leaf-eating Caterpillars ...		o	gg				o	o	o
Mealy-Bug		o	o				o	r	gg
LIMES AND OTHER CITRUS TREES									
Scale Insects	gg	gg	gg	L	L	gg			
Bush Borer	o	o	r	r	o	l			gg o
Root Borers, Root Grubs ...	o	o	r	o	o	o			
Orange Moth	–	–	–	L	–	–			gg
Green Weevil	o	o	r	o	o	o			o
ONIONS.									
Caterpillar Cutworms						gg			
Thrips						r			gg gg
Hard Back Grubs						r			o
SUGAR-CANE.									
Moth Borer	gL	gg	gg		l	gg	gg	gg	gg
Weevil Borer	o	r	gg		o	gg	o	r	o
Root Borer Diaprepes	o	o	gg		r	o	r	r	r
„ „ Exophthalmus ..	o	o	?		r	r	r	r	r
Termites	o	o	o		o	r	o	o	gg
Hard Back Grubs	o	o	o		o	L	o	o	o
Froghopper	L	–	–		–	–	–	–	–
Mealy-Bug	o	o	gg		o	o	o	gg	gg
Grashoppers	o	o	r		o	r	L	L	o
Beetle	o	o	r		o	o	o	o	o
Cane Fly	o	o	o		o	o	o	o	r

INSECT PESTS.—(*Concluded.*)

	Grenada.	St. Vincent.	St. Lucia	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Virgin Islands.
SWEET POTATOES.									
Scarabee – Jacobs		r	o	o		gg L	r	r	r
Caterpillars		o	L	o		gg L	o	l	L
Thrips		o	r	o		o	o	o	o
Red Spider		r	o	o		o	o	o	o
Slug		o	L	gg		o	o	o	o
Bush Bugs		o	gg	o		o	o	o	o
Hard Back Grubs		o	o	o		r	o	o	o
TANNIAS, DASHEENS, EDDOES.									
Hard Back Borer			gL						
Lacewing Bug			gg						
YAMS.									
Scale Insects	L	gg	gg			o gg	r		
Slugs	o	o	gg			o	o		
Hard Back Grubs	o	o	o			r	o		

	Grenada.	St. Vincent.	St. Lucia	Dominica.	Montserrat.	Antigua.	St. Kitts.	Nevis.	Virgin Islands.
YAMS BANANAS AND PLANTAINS.									
Marasmius Rot.	o		G						
CACAO.									
Root Diseases	l		gg L						
Canker	g L		G	g L					
Black Rot of Pods	o		gg	gg					
Brown Rot of Pods	g L		ggg	gg gg					
Die-back and Stem Diseases ..	l		G	gg gg					
Pink Disease	o			o					
Thread Blights	o		l	o					
Horse-hair Blight	l								
COCO NUTS.									
Bud Rot	o	o	l	o				l	
Red Ring Disease	g L	o	o	o					
Leaf Diseases	o	o	l	o	o	o	o	o	o
CORN (INDIAN).									
Rusts	o	gg	gg	o	o	gg	o	gg	gg
Smut	l	gg	o	o	o	l	l	l	l
Root Disease						l	o	o	r
COTTON.									
Soft Rot of Bolls	o	gg	o	o	gg	o	l	o	o
West Indian Leaf Mildew ...	o	gg	gg	o	L	gg	gg	gg	gg
Bacterial Boll Disease	o	o	o	o	o	o	o	gg	l
Angular Leaf Spot	o	g	l	o	?	o	l	gg	o
Black Arm	o	o	o	o	o	o	o	o	o
Internal Boll Disease	o	g	o	o	r	gg	r	gg	G
GROUND NUTS.									
Root Disease	o						o		
Leaf Rust	o	g	g	o	o	o	o	l	o
Leaf Spot	o						o		

PLANT DISEASES —(*Concluded.*)

	Grenada.	St. Vincent.	St. Lucia	Dominica.	Montserrat	Antigua.	St. Kitts	Nevis.	Virgin Islands
LIMES AND OTHER CITRUS TREES									
Black Root Disease	o	o	r	l				o	
Red Root Disease	o		o	l				o	
Unidentified Root or Collar Disease	g L		o	r	o	o		o	
Die-back	G	o	l	L	o	o	o	o	o
Seedling Diseases	l	o	L	r	r				
ONIONS.									
Bacterial Disease				r		r	o	o	r
SUGAR-CANE.									
Root Disease	o	g	G	o	o	g	g	g	g
Rind Fungus	o	g g	g	o	o	g	o	l	o
Red Rot	o	o	o	o	o	o	o	o	o
Pine-apple Diseases	o	r	r	o	o	r	o	o	o
SWEET POTATOES.									
Root Disease	o				o		o	o	
White Rust	o							o	o
YAMS.									
Tuber Disease	o				o	o	o		
Wilt Disease	r				o	o	o		
PHANEROGAMIC PARASITES.									
Love Vine	g L	g	g L	r	g	r	l	r	r
Mistletoe	g L	o	g	l	o	o	o	o	r

[Page 125 to 271 issued 31st March 1922]

TRINIDAD.

Head Office.

Director of Agriculture ...	W. G. Freeman B.Sc., (Lond.) A.R.C.S., F.L.S.
Assistant Director	W. Nowell, D.I.C.
Chief Clerk	J. E. Scheult.
Librarian & Statistical Clerk ...	M. Dhein.
Clerks	F. Chookolingo, Ali Hosein, E. A. Thomas, P. John.

Botanical and Plant Industries.

Economic Botanist	A. G. Bailey, B.A. (Oxon.).
Cacao Agronomist & Supt: River Estate ...	L. Scheult, B.Sc., (Edin.)
Sugar Agronomist & Supt: St. Augustine Experiment Station	Vacant.
Assistant Botanist	W. E. Broadway.
Assistant to Cacao Agronomist	N. Raphael.
Herbarium Assistant	Miss P. McLean.

Royal Botanic Gardens, Trinidad.

Curator	R. O. Williams.
Overseer	J. Pinder.

Botanic Station, Tobago.

Curator	R. J. Link.
Foreman	J. Blackman

River Estate (Cacao).

Manager	R. O'Connor.
Clerk and Overseer	S. Arneaud.

St. Augustine Experiment Station (Sugar, Etc.)

Assistant Superintendent ...	L. A. Brunton.

Plant Diseases and Pests.

Plant Pathologist	W. Nowell, D.I.C.
Entomologist (General)	F. W. Urich, F.E.S., C.M.Z.S.
Mycologist	F. Stell.
Chief Inspector, Plant Protection Ordinance	C. F. Wood.
Assistant to Mycologist ...	W. Buthn.
Assistant to Pathologist	M. Daly.
Assistant to Mycologist	George Hodge.
Assistant to Entomologist	D. Farrell.

Chemical Department.

Agricultural Chemist	J. de Verteuil, F.I.C., F.C.S.
Assistant	L. Daniel

Stock.

Govt. Veterinary Surgeon	H. V. M. Metivier, O.B.E. M.R.C.V.S., B.Sc.
Manager, Government Farm, Trinidad ...	J. McInroy.
Do. do. Tobago ...	R. J. Link.
Clerk and Overseer (Trinidad) ...	J. C. Hay.
Pasture Keeper (Queen's Park Savannah) ...	B. Hall.

Agricultural Advisers.

		Residence.
F. D. Davies ...	Tobago	Scarborough.
C. M. Roach ...	County of St. George	San Juan.
L. Mota ...	Counties of Nariva and Mayaro ...	Rio Claro.
R. W. M. Leacock	Counties of St. Andrew & St. David ...	Sangre Grande.
J. J. Beard ...	County of St. George	Carenage.
T. Boodansingh ...	County of Victoria	Princes Town.
A. Pena (Acting) ..	County of St. Patrick	Siparia.

Ground Provisions Depot.

Manager	R. S. Redman

GRENADA.

AGRICULTURAL DEPARTMENT.

Board.

Chairman (ex officio ... ... The Colonial Secretary.
Two officials and six other members appointed by Governor.

Staff.

Superintendent of Agriculture ...	W. O'BRIEN DONOVAN (Actg).
Agric. Instrs.	E. L. CHERUBIM.
Clerk	S. F. HURLEY.
Foreman, Botanic Station ...	J. C. CALLENDER.

ST. LUCIA.

Botanic and Agricultural Experiment Stations and Education

Agric. Supdt. and Land Officer ...	A. J. BROOKS, F.I.., F.C.S., etc.
Agricultural Assistant	E. BUCKMIRE.
Overseer and Agricultural Officer, Inspector Agric. Credit Societies.	R. W. NILES.
Foreman and Agric. Instr. ...	E. B. SMITH.
Junior Agric. Assistant	M. GEORGE.
Clerk to Agricultural Superintendent ...	W. W. ARNO.
Clerk Government Lime Juice Factory ...	MISS A. M. Y. WARRICAN.

LEEWARD ISLANDS.

Government Chemist and Supt. of Agric.	A. E. COLLENS, F.I.C., F.C.S,
Assistant Govt. Chemist	F. H. S. WARNEFORD, B.A., B.Sc., A.I.C., F.C.S.
Junior Assistant	E. A. THOMPSON.
2nd Junior Assistant	K. A. ELDRIDGE (Acting).
Messenger	ARTHUR COLBOURNE.

DOMINICA.

Botanic and Agricultural Experiment Stations and Education.

Agric. Superintendent and Curator ..	JOSEPH JONES.
Assistant Curator	ALFRED KEYS.
Foreman	F. J. BAPTISTE.
Overseer	D. A. GREEN.
Clerical Assistant	W. G. HUTTON.
Agricultural and Science Master ...	H. B. PIDDUCK

ANTIGUA.

Botanic and Agricultural Experiment Stations and Education.

Agricultural Superintendent ...	F. G. HARCOURT.
Land Officer and Agricultural Instructor	E. ELDRIDGE.
1st Assistant for Agric. Experiments ...	(vacant)
2nd Assistant for Agric. Experiments ...	A. C. THOMPSON,
Agric. and Science Master... ...	CAPT. A. C. RADFORD, B.A.
Clerk	MISS G. EDWARDS.

ST. VINCENT.

Botanic and Agricultural Experiment Stations and Education.

Agricultural Sup'dent and Inspector Agricultural Credit Societies	T. P. JACKSON.
Assistant Superintendent	(vacant)
Cotton Inspector	L. A BROWN.
Foreman (Exp. Station.) F. A. SIMMONS	(Bot. Stn.) E. BANFIELD.
Officer in Training	C. A. MARSHALL.
Clerical Assistant	MISS W. E. LINLEY.
Agricultural and Science Master ...	O. D. C. POTTER.

Government Ginnery and Granary.

Manager	S. B. ISAACS.
Granary Committee of Magagement ...	HON. L. PUNNETT and five members.

MONTSERRAT.

Botanic Station.

Curator...	W. ROBSON.
Assistant Curator	A. W. GALLWEY.
Foreman	J. H. ALLEN

ST. KITTS-NEVIS.

Botanic and Agricultural Experiment Stations and Education.

Agricultural Sup'dent	F. R. SHEPHERD.
Asst. Agric. Supt. & Chemist ...	R. E. KELSICK
Foreman	A. S. PODD.
Agricultural Instructor Nevis ...	W. I. HOWELL.

BRITISH VIRGIN ISLANDS.

Curator	C. A. GOMEZ.
Overseer and Foreman	S. A. RHYMER.
Clerk	B. A. PICKERING.

BRITISH HONDURAS.

Botanic Station.

Curator	—

JAMAICA.

DEPARTMENT OF AGRICULTURE.

Director and Island Chemist ...	THE HON. H. H. COUSINS, M.A. (OXON.), F.C.S.

Government Laboratory.

Microbiologist	—
Entomologist	C. C. GOWDEY, B.Sc., F.E.S., F.Z.S.
Deputy Island Chemist	
Sugar Chemist and Superintendent of Field Expts.	A. C. LAWSON.

Public Gardens and Plantations.

Superintendent	—
Superintendent of Expt. Station ...	P. W. MURRAY.

Agricultural Education.

Head-master, Farm School ...	R. S. MARTINEZ.
Assistant Masters	H. R. ANGELL, A. F. THELWELL.
Veterinary Consultant	G. O. RUSHIE GRAY, B.Sc. (Lond.), M.R.C.V.S.
Travelling Instructors—WM. CRADWICK, JAMES BRISCOE.	
Superintendent Lititz Experiment Farm ...	L. L. CARRINGTON, Dp. Ag.
Inspectors of Plant Diseases	STANLEY SCUDAMORE. J. B. SUTHERLAND. H. G. COOTE.

Head Office.

Clerk	GEORGE D. GOODE, Dp. Ag.
Clerical Assistants ...	J. B. HIGGINS. W. E. WATSON
Superintendent's Clerk	MISS E. MARSON.

AGRICULTURAL NEWS.

The Fornightly Illustrated Review of the Imperial Department of Agriculture for the West Indies.

The principal features of the AGRICULTURAL NEWS are as follows :—

Editorials on topics of current interest in the Tropics.

Notes and Comments on Miscellaneous subjects.

Articles dealing with

The Sugar Industry ;
Fruit and Fruit Trees (Citrus, Cacao, Coco-nuts, etc.) ;
Cotton.

Special features include

Insect Notes (by the Entomologist) ;
Fungus Notes (by the Mycologist) ;
Down the Islands (Items of local interest) ;
Gleanings' page ;
Reviews of new books and Departmental Reports ;
Miscellaneous Notes ;
Market Reports.

Letters and matter for publication, as well as all specimens for naming, should be addressed to the Commissioner, Imperial Department of Agriculture, Head Office, Barbados.

All applications for copies of the Agricultural News should be addressed to the Agents, and not to the Department. A complete list of the London and Local Agents is as follows :—

London : Messrs. Dulau & Co., Limited, 34-36, Margaret Street, Cavendish Square, W. 1.
West India Committee, 15, Seething Lane, E. C., 3.
Barbados : Advocate Co., Ltd., Bridgetown.
Jamaica : The Educational Supply Company, 16, King Street, Kingston.
British Guiana : The Argosy Co., Ltd., Georgetown.
Trinidad ; Messrs. Muir, Marshall & Co., Port-of-Spain.
Tobago : Mr. C. L. Plagemann, Scarborough.
St. Vincent : Mr. Floris Simmons, Experiment Station.
Grenada : Messrs. Thos. Lawlor & Co., St. George.
St. Lucia : Mr. R. W. Niles, Botanic Station.
Dominica : Mr. W. G. Hutton, Roseau.
Montserrat : Mr. W. Robson, Botanic Station.
Antigua : Mr. S. D. Malone, St. John's.
St. Kitts : The Bible & Book Supply Agency, Basseterre.
Nevis : Mr. W. I. Howell, Experiment Station.
Canada : Lewis W. Clemens, 801, Yonge Street, Toronto.
Bahamas : Mr. N. D. Sands, Board of Agriculture, Nassau.

The price of the *Agricultural News* is 1*d*. per number, post free. 2*d*. Annual Subscription, payable to Agents, 2*s*. 2*d*.—post free, 4*s*. 4*d*. Volumes V, VI, VII, VIII, IX, X, XI, XII, XIII, XIV, XV, XVI, XVII, XVIII and XIX complete, with title page and index as issued—Price 5*s*. each, post free. Some numbers of the earlier volumes are out of print, and therefore these volumes cannot be supplied complete. The scale of charges for Advertisements may be obtained on application to the Agents.

Advocate Co. Ltd., Barbados.